ERDA-76/163/1

Building Energy Handbook

Volume 1
Methodology for Energy Survey and Appraisal

December 1976

Prepared For:
Energy Research & Development Administration
Division of Building and Community Systems
Under Contract No. E(49-1)-3853

Project Managed By:
Division of Facilities and Construction Management

The BUILDING ENERGY HANDBOOK consists of two volumes:

Volume 1: Methodology for Energy Survey and Appraisal (ERDA 76/163/1)

Volume 2: Forms for Energy Survey and Appraisal (ERDA 76/163/2)

Availability and price information are indicated below. Questions concerning the contents of or pertaining to this publication should be directed to the Division of Facilities and Construction Management, ERDA Headquarters, Washington, D.C. 20545.

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy: $10.00
Microfiche: $ 2.25

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CHAPTER 1

EXECUTIVE SUMMARY

SECTION A - INTRODUCTION

The United States Energy Research and Development Administration (ERDA) ENERGY HANDBOOKS present guidelines to investigate and analyze energy usage, to identify energy saving opportunities, and to recommend and evaluate energy conservation measures at ERDA facilities. Pope, Evans and Robbins Incorporated, Consulting Engineers, (PER) was selected to prepare these HANDBOOKS under ERDA Contract No. E(49-1)-3853.

The methodology was developed and tested while conducting an actual energy conservation survey at a major ERDA installation: Argonne National Laboratory, ANL-East, at Argonne, Illinois. It is anticipated that the methodology will be further developed, and the HANDBOOKS appropriately revised, as additional ERDA facilities are surveyed. It is hoped that the HANDBOOKS' methodology will also prove useful for conducting energy conservation surveys of facilities of other Federal, state and local agencies and of the private sector.

The survey methodology is presented in two parts. The SITE ENERGY HANDBOOK, published as ERDA-76/131/1 and ERDA-76/131/2, covers site energy and utility distribution systems, and the BUILDING ENERGY HANDBOOK pertains to the interior systems. The interface is essentially the traditional "five feet outside the building line", assuming due allowance for meter location, system interaction, etc.

The HANDBOOKS contain (1) discussion of techniques for conducting energy surveys, and (2) forms for gathering and collating data. The intent is that those forms germane to a specific survey will be removed temporarily from the HANDBOOK(S) and reproduced in the quantities needed for actual field use.

SECTION B. PURPOSE OF BUILDING ENERGY HANDBOOK

The purpose of the BUILDING ENERGY HANDBOOK is:

(1) to provide guidelines and forms to identify and select for detailed investigation those buildings which offer the greatest potential for energy conservation,

(2) to identify and evaluate significant energy conservation opportunities (ECOs) within selected buildings, and

(3) to rank technically feasible ECOs based on economics.

The BUILDING ENERGY HANDBOOK is based on PER's analysis of Building 212 at ANL-East, with the intention that it be suitable or adaptable for use at other laboratory-office type buildings.

SECTION C. SCOPE OF BUILDING ENERGY HANDBOOK

The BUILDING ENERGY HANDBOOK covers all building energy systems including energy entering, converted, distributed, consumed and leaving the building. Energy systems considered include electricity, steam, hot air, recirculated hot water, chilled water, once-through hot and cold water, compressed air and waste energy systems.

SECTION D. CONTENTS OF BUILDING ENERGY HANDBOOK

The BUILDING ENERGY HANDBOOK consists of two volumes:

Volume 1: Methodology for Energy Survey and Appraisal and Energy Conservation Opportunities.

Volume 2: Forms for Energy Survey and Appraisal

Volume 1 of the BUILDING ENERGY HANDBOOK contains the following chapters.

Chapter 1: Executive Summary

Chapter 2: Selection of Buildings for Detailed Energy Study

Chapter 3: Building Energy Appraisal

Chapter 4: Survey and Appraisal of Building Energy Conservation Opportunities

Chapter 5: Energy Conservation Opportunities

Appendix 1: ECO Related Questions

Appendix 2: Electrical Energy Appraisal

Appendix 3: Manual Energy Calculations for Building 212 at Argonne National Laboratory

Appendix 4: Appendix to Chapter 5

Appendix 5: References

Volume 2 of the BUILDING ENERGY HANDBOOK contains the following chapters:

Chapter 1: Introduction

Chapter 2: Forms for Selection of Buildings for Detailed Energy Study

Chapter 3: Forms for Building Energy Appraisal

Chapter 4: Forms for ECO Survey and Appraisal

SECTION E. SUMMARY OF BUILDING ENERGY HANDBOOK

This BUILDING ENERGY HANDBOOK is based on a three-phased approach to building energy conservation: selection of buildings for detailed energy study; building energy appraisal; and energy conservation opportunity (ECO) survey and appraisal. The methodology of each phase is illustrated in Exhibits A, B and C, which are cross-referenced to applicable forms and data sources.

1E.1 Selection of Buildings for Detailed Energy Study: The first phase, illustrated in Exhibit A and presented in Chapter 2, consists of six steps:

1. Data gathering and synthesis
2. Establishing of selection criteria
3. Preliminary selection of buildings
4. Building questionnaire
5. Walk-through survey
6. Building selection

The HANDBOOK provides forms (Form 2-1) for gathering basic data concerning the characteristics and energy consumption of each building. Guidelines for the establishment of selection criteria and preliminary selection of buildings are presented. In order to obtain specific data concerning the selected buildings energy systems, a questionnaire is distributed to responsible operating personnel. Guidelines for preparing and distributing this questionnaire, as well as a typical questionnaire (Form 2-2) are included. Following evaluation of the questionnaires and review of all available information, each building selected is surveyed to verify existing, and collect additional information; obtain first-hand knowledge of the energy systems; and identify potential ECOs. An ECO checklist is provided to assist in identifying possible ECOs (Form 2-3). The HANDBOOK presents guidelines to assist in the final selection of buildings with high energy conservation potential for detailed study under subsequent phases of the energy conservation program.

EXHIBIT A

SELECTION OF BUILDINGS FOR DETAILED ENERGY STUDY

WORK FLOW DIAGRAM

• STEP	1	2	3	4	5	6
• TASK DESCRIPTION	DATA GATHERING AND SYNTHESIS →	ESTABLISH SELECTION CRITERIA →	PRELIMINARY SELECTION OF BUILDINGS →	BUILDING QUESTIONNAIRE →	WALK-THROUGH SURVEY →	BUILDING SELECTION
• APPLICABLE FORM (CHAPTER 2, VOLUME 2)	• BUILDING DATA SUMMARY SHEET (FORM 2-1)			• BUILDING QUESTIONNAIRE (FORM 2-2)	• ECO CHECKLIST (FORM 2-3)	
• BACKGROUND DATA	• MAPS • BUILDING LISTS • DRAWINGS • UTILITY RECORDS		• SELECTION CRITERIA	• BUILDING PERSONNEL EXPERTISE • BUILDING RECORDS	• ECO RELATED QUESTIONS (APPENDIX I, VOL. I) • BUILDING RECORDS	• SELECTION CRITERIA • BASIC BUILDING DATA • BUILDING QUESTIONNAIRE • ECO CHECKLIST • PREVIOUS ENERGY CONSERVATION PROGRAMS

1E.2 Building Energy Appraisal: The second phase, illustrated in Exhibit B and presented in Chapter 3, consists of eight steps:

1. Obtain and review basic data.

2. and 3. Develop preliminary energy flow and balance diagram.

4. Perform actual building energy appraisal and develop actual building energy indices.

5. Reconcile with known totals.

6. Complete energy flow and balance diagrams.

7. Develop base building energy indices.

8. Identify ECOs.

A preliminary building energy flow and balance diagram is prepared using data obtained in the first phase for energy entering, converted, distributed, consumed and leaving the building. The diagram shows the qualitative and, to the extent possible, quantitative interrelationships among various energy systems. Form 3-1 assists in the structuring of available data in a format suitable to the preparation of the preliminary diagram.

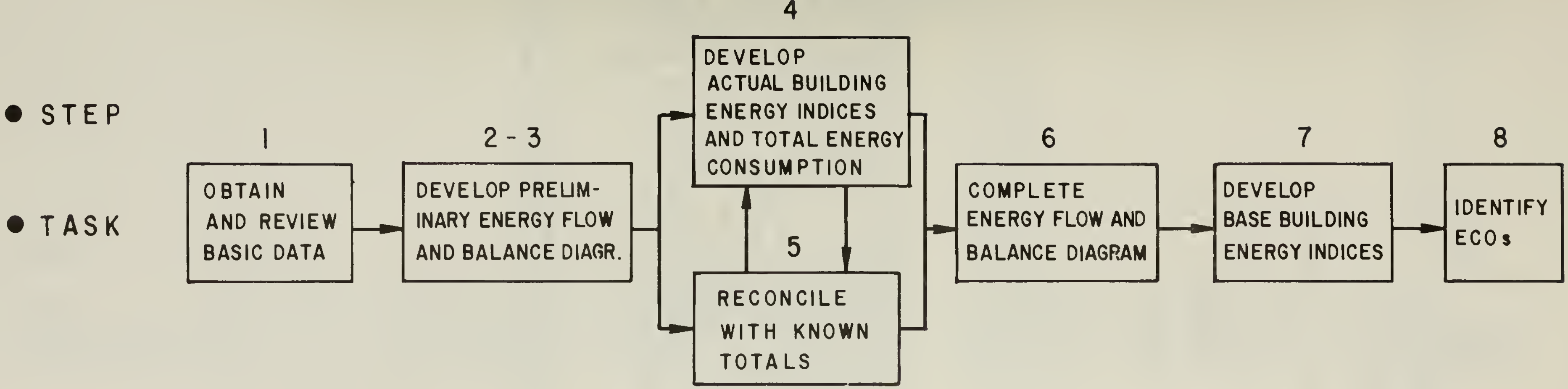
Appraisal of building energy systems may be performed through the determination of energy indices for various building energy systems. The system energy index represents the energy consumed in that system related to a specific building characteristic, such as square feet of floor area serviced by the system. Forms 3-2 and 3-3 assist in determination of energy indices for actual and base (similar structure and function under ideal conditions) building systems.

The actual building energy data so determined are used for reconciliation with known energy totals derived from meter readings, building utility records, etc. When estimated totals do not agree with known totals, assumptions are revised until balance is achieved. Reconciled actual energy data may be synthesized in Form 3-4 for use in the preparation of the building energy flow and balance diagram.

Potential ECOs are determined by comparing actual and base building energy indices.

EXHIBIT B

BUILDING ENERGY APPRAISAL
WORK FLOW DIAGRAM



• **FORM** (CHAPTER 3, VOLUME 2)

- PRELIMINARY ENERGY APPRAISAL (FORM 3-1)
- ACTUAL BUILDING ENERGY INDEX (FORM 3-3)
- ENERGY FLOW DIAGRAM SYNTHESIS (FORM 3-4)
- BASE BUILDING ENERGY INDEX (FORM 3-2)

• **BACKGROUND DATA**

- BUILDING QUESTIONNAIRE (CHAPTER 2, VOLUME 2)
- ECO RELATED QUESTIONS (APPENDIX I, VOLUME I)
- BUILDING ECOs (CHAPTER 5, VOLUME I)

1E.3 ECO Survey and Appraisal: The third phase, illustrated in Exhibit C and presented in Chapter 4, consists of six steps:

1. Preliminary ECO appraisal
2. In-depth survey form refinement
3. ECO oriented in-depth survey
4. Technical appraisal of ECOs
5. Economic appraisal of ECOs
6. ECO ranking

An optional seventh step includes the final refinement of the energy flow diagram based on the additional data obtained during the in-depth survey.

A preliminary evaluation of ECOs identified is performed using data gathered during the preceding phases. An in-depth survey is performed to obtain additional, or more accurately define existing ECO related data using Form 4-1. Technical evaluation of the ECOs is performed based on the ECO descriptions in Chapter 5. Economic evaluation and ranking of the technically feasible ECOs is performed based on the methodology presented in "Life Cycle Costing Emphasising Energy Conservation" (ERDA - 76/130). Forms 4-2 and 4-3 contain a summary of the data required and the procedures involved in the economic appraisal of building ECOs.

Building ECO appraisal may be performed manually or on computer. Chapter 4 contains guidelines for selection of the most appropriate mode of calculation.

EXHIBIT C

ECO SURVEY AND APPRAISAL

WORK FLOW DIAGRAM

● STEP	1	2	3	4	5	6	7
● TASK DESCRIPTION	PRELIMINARY ECO APPRAISAL	IN-DEPTH SURVEY FORM REFINEMENT	ECO ORIENTED IN-DEPTH SURVEY	TECHNICAL APPRAISAL OF ECOs	ECONOMIC APPRAISAL OF ECOs	ECO RANKING	REFINED ENERGY FLOW AND BALANCE DIAGRAM (OPTIONAL)
● APPLICABLE FORM (CHAPTER 4, VOLUME 2)		● IN-DEPTH SURVEY FORMS (FORM 4-1)	● REFINED IN-DEPTH SURVEY FORMS		● ECO-ECONOMIC APPRAISAL FORMS (FORM 4-2)	● ECO RANKING AND ECONOMIC APPRAISAL SUMMARY (FORM 4-3)	
● BACKGROUND DATA		● ECO RELATED QUESTIONS (APPENDIX I, VOLUME I)		● BUILDING ECOs (CHAPTER 5, VOLUME I)			

CHAPTER 2

SELECTION OF BUILDINGS FOR DETAILED ENERGY STUDY

SECTION A. GENERAL CONSIDERATIONS

2A.1 Introduction. The major purpose of ERDA's current energy studies is to identify energy conservation opportunities (ECOs), i.e. equipment or procedural changes which may result in reduction of energy consumption and in associated cost savings larger than the investment required to implement the changes.

It would be impractical to survey the energy consumption and identify ECOs in each of the buildings on an ERDA facility. A methodology was developed to identify and select for investigation those buildings which offer the greatest potential for energy conservation, thereby making best use of available funds and personnel for energy conservation.

This chapter describes the methodology and criteria for selecting buildings for energy studies.

2A.2 Methodology. A six step approach to building selection, described in Section B, and presented schematically in Exhibit A in the Executive Summary, is recommended.

- Step 1 - Data Gathering and Synthesis of Available Data
- Step 2 - Establishing of Selection Criteria
- Step 3 - Preliminary Selection of Buildings
- Step 4 - Preparation, Distribution and Evaluation of Building Questionnaire
- Step 5 - Walk-Through Survey
- Step 6 - Selection of Buildings for Detailed Energy Study.

2A.3 Hard Vs. Soft Data. Hard data are recorded and quantified information. Soft data are estimates and unquantifiable data. Hard data include meter readings and characteristics of the buildings such as floor area and architectural features as well as size and type of equipment.

2A.4 Energy Study Team Organization. It is envisioned that the energy study will be conducted by at least a mechanical engineer and an electrical engineer qualified to evaluate heating, ventilating, air conditioning, plumbing and electrical systems.

2A.5 Input by Facility and Building Management Personnel. The participation and cooperation of the facility operations personnel and of the buildings' management staff is critical to the quality of the building selection procedure and development of ECOs. Since in most applications limited hard data are available, soft data will have to be developed and the energy study team will be largely dependent on data provided by building operations and maintenance staffs. During the walk-through survey, the energy study team should be accompanied by building personnel to provide data on operation and maintenance and on the feasibility of the potential ECOs identified.

SECTION B. STEP BY STEP PROCEDURE

2B.1 Step 1. Data Gathering and Synthesis of Available Data. Basic available data on energy consumption and building characteristics should be collected. The building identification number, name, function, type of construction and floor area should all be readily available. Total annual consumption of fuels, electricity, steam, water, etc., may be available for at least the principal buildings. At some facilities, however, minimal data on energy consumption of individual buildings will be found.

The energy study team should find out what records are available and then request the facility to provide copies of such items as building lists, recent utility reports, maps, site energy reports, recent energy conservation reports, and latest master plan. The use of Form 2-1 in Chapter 2 of Volume 2 will help in synthesizing the most significant available data.

2B.2 Step 2. Establishing of Selection Criteria. The energy study team should establish the criteria to be used for the preliminary energy evaluation of all buildings on the site and the selection of buildings for detailed energy studies. These criteria should be discussed with the facility management.

As a general rule, any building that either

1) represents 5% or more of the gross site building square footage or

2) consumes more than 2% of the total energy entering the site should be considered for detailed study.

The following additional criteria are suggested:

3) The Energy Index (Energy Budget) Concept: The energy index strives to indicate the energy efficiency of a facility, a building, or an energy system by identifying the total energy consumption and its components and relating them to one or more relevant facility characteristics such as square feet of area, cubic feet of air conditioned or heated space or number of occupants.

   The concept of identifying an existing building as an energy waster and quantifying the extent of waste simply by comparison of actual consumption with a guideline energy index, presupposes that the building structure, function, occupancy, usage, building energy systems, etc., are comparable to the prototype or base guideline building.

For energy indices expressed in Btu equivalent, both source and building boundary Btu equivalents should be considered.

The energy index should be used as only one of several criteria in establishing a ranking of buildings for detailed energy studies.

4) <u>High Total Energy Consumption</u>:
High total energy consumption (defined as greater than 20 x 10^9 Btu/year) is indicative of a potential for worthwhile ECOs and in most cases promises a high probability of substantial savings even with a modest percentage of improvement.

5) <u>Wide Range Between Maximum and Average Demands:</u>
A wide range between maximum and average demands which cannot be accounted for by obvious factors such as seasonal or day/night changes may indicate the possibility of more efficient energy and equipment usage. The range may be readily identified by the ratio of monthly energy usage to monthly peak demand (e.g. Kwh/Kw for electricity). The optimum monthly ratio for continuous (24 hour) use is 720 and the point normally indicative of potential savings is 400 or less. Proportionate adjustments for shorter usage periods should be made.

6) <u>Similarity to Other Buildings on the Site:</u>
Some buildings may be identical or have identical features to other buildings. Residential buildings, prefabricated buildings, office and laboratory buildings are examples. Substantial total energy savings may be made by applying ECOs determined in the study of one building to other buildings of the same or similar type. In selecting which building of a group of similar buildings should be studied, the number of typical features, data available, individual metering, etc. should be considered. Where buildings are similar in configuration but different in function, ECOs determined in one building may not necessarily be applied to another.

7) <u>Recognizable ECOs:</u>
Low cost, easily recognized ECOs are obvious reasons for selecting a building for detailed study. Sometimes smaller buildings are high energy wasters and may offer better opportunities than buildings consuming large amounts of energy but with relatively efficient systems and operating procedures. Therefore the

recognition of ECOs through evaluation of survey data and information provided by building and facility operations personnel is probably the most important basis for building selection.

The most common ECOs which are likely to be found in buildings are listed at the beginning of Chapter 5. The major areas which should be investigated are:

- Lighting
  - Lighting levels excessive for the function;
  - Replacement of low efficiency lights with high efficiency lights;
  - Automatic or manually scheduled shutdown when not required.

- HVAC Systems
  - Unnecessary fresh air cooling and reheat;
  - System control;
  - Replacement or modification of inefficient equipment;
  - Shutdown or cut-back during non-working hours.

- Sealing and Insulation
  - Building openings;
  - Old ventilation systems left unsealed;
  - High ceilings;
  - Excessive glass areas;
  - Uninsulated steam, hot water and chilled water lines;
  - Under or un-insulated building walls or roofs.

- Steam Lines
  - Excessive leakage;
  - Excessive flashing to atmosphere;
  - Mains shutoff during periods of no steam demand.

- Plumbing
  - Domestic hot water temperature;
  - The use of the water supply for preheating or cooling;
  - Water pressure;
  - Flow controls;
  - Shutdown or cut-back of hot water system during non-working hours.

- Waste heat recovery from:
  - Boiler and furnace flues;
  - Ventilation to atmosphere;
  - Condensers;
  - Turbine exhausts.

8) Previous Energy Studies:
The results of previous energy studies for individual or categories of buildings or systems should be taken into account in deciding whether the building warrants further energy survey and analysis.

9) Restrictions by ERDA:
ERDA may limit access to, or modifications within, some buildings due to the critical nature of the work being conducted in those buildings. These limitations often preclude a successful in-depth energy study and/or implementation of ECOs. Such buildings should be the subject of specialized energy studies performed directly by, or in close cooperation with local personnel. Such specialized energy studies are outside the scope of this HANDBOOK.

10) Expected Building Life:
The site master plan should be consulted. Any plans for phasing out, demolition or major changes to a building should be considered before selecting that building for detailed energy study.

11) Similarity of Energy Systems:
A number of energy systems are likely to be common to a number of buildings. Examples are double duct or terminal reheat air conditioning systems, steam heating, once through ventilation. Each of these systems may present particular ECOs. To take advantage of the leveraging effect of invested study time to energy savings potential, buildings selected for study should include as many typical systems as possible.

2B.3 Step 3. Preliminary Selection of Buildings. Based on general information from site records gathered within Step 1, buildings should be grouped by function, type of construction, and similar major energy usages. The buildings should then be ranked according to total floor area. Small, one-of-a-kind buildings consuming less than 5×10^9 Btu/year should be eliminated from immediate consideration. Other one-of-a-kind, special function, restricted access buildings should be deferred for separate consideration. Two or three of the physically largest and/or largest energy consuming, most representative buildings

in each category should then be selected. This procedure is expected to eliminate about eighty percent of the buildings on the site and leave a manageable number of buildings for further investigation.

2B.4 Step 4. Preparation, Distribution and Evaluation of Building Questionnaire.

2B.4.1 Building Questionnaire. The collection of specific energy information for a number of complex buildings can be considerably simplified by the use of a questionnaire given to the building operating staff, completed by them, and returned to the energy study team. The major advantage of this approach is that it utilizes the most knowledgeable facility personnel to provide basic energy data, resulting in a reduced time and effort for data gathering.

Some of the data in the Building Questionnaire may be available from records collected within Step 1. All such data should be indicated on the Building Questionnaire by the energy study team prior to the distribution of the Questionnaire. This action reduces the effort required from the building staff in filling out the Questionnaire and permits a checking of the general record data by building personnel.

The Questionnaire should reveal sufficient information about the building systems and operation to give a good indication of whether or not the building is an efficient energy user. The Questionnaire therefore permits a classification of buildings in terms of energy efficiency.

The energy study team should review the data provided by the Questionnaire, before the walk-through survey. This familiarizes the team with building specifics and often permits formulation of ideas for ECOs before the actual survey of the building. As a result, the walk-through survey will be better defined in scope and its effort minimized.

The successful completion of a Building Questionnaire requires the cooperation of the building supervisors and follow-through action by the energy study team.

A typical Building Questionniare is shown in Chapter 2, Volume 2, Form 2-2. The Questionnaire will have to be adjusted to suit conditions at the particular building. It is important that only the minimum information necessary to make a building selection be requested in the Questionnaire. The information requested should be in a simple, concise form and should only be of the type that building operation personnel could be expected to answer from their records or personal knowledge.

2B.4.2. Meeting. It is suggested that at least one meeting be held with the facility operation personnel and with representatives of the staff of those buildings selected within Step 3. The purpose of the meeting should be to describe the building selection procedure and present guidelines for filling out the Building Questionnaire. The meeting should be attended by the people who will be responsible for the completion of the Questionnaire and will be asked to provide input to the selection process, such as building managers and building maintenance area supervisors.

2B.4.3. Distribution and Collection of Building Questionnaires. The distribution and collection of Building Questionnaires should be arranged through appropriate facility officials and be made over the signature of the Plant Manager. This indicates management support and provides the necessary line authority to have the Questionnaires completed within a reasonable time. The survey team should follow up to ensure the return of the Building Questionnaires, working through a designated responsible official.

2B.4.4. Evaluation of Completed Building Questionnaires. It is unlikely that the Building Questionnaires as returned will be complete. Some of the data requested may not be available, some questions may be misinterpreted, or some answers may be incomplete. Any important missing information should be identified and obtained during the walk-through survey.

2B.5. Step 5. Walk-Through Survey. The purpose of the walk-through survey is:

1) To collect any necessary information which was not included in the returned Building Questionnaires.

2) To check any questionable information provided by the Building Questionnaire.

3) To obtain some first-hand knowledge and acquaintance with the building and its energy systems.

4) To determine whether certain previously identified ECOs have a good or a poor possibility of being applied to the particular building.

2B.5.1 Preparation. It is envisioned that each building will be surveyed in one working day or less. The team should perform at least the following activities prior to the walk-through survey:

- Obtain and review buildings' architectural, mechanical and electrical drawings;

- List missing or doubtful information in the returned Building Questionnaires;

- Identify possible ECOs. The ECO Checklist, Form 2-3 in Chapter 2 of Volume 2, is designed to assist the team in identifying and assessing individual ECOs.

- Prepare specific ECO related questions. Having identified which ECOs will be investigated during the survey it is suggested that the team read the ECO Related Questions listed in Appendix 1. These will help identify major items to check in order to assess the potential of a particular ECO.

2B.5.2 Scheduling. A survey program should be scheduled and specific appointments arranged with the management of each building to be surveyed. The supervisors should be advised in advance of the purpose of the visit so that they can ensure participation of appropriate knowledgeable personnel. The results of the study will to a large extent depend on the participation of these people in the walk-through survey and at the related work session.

2B.5.3 Data Collection. It is not intended that all questions be answered in either the Building Questionnaire or the list of ECO Related Questions. Sufficient data should be collected only to permit evaluation of the building's energy consumption and conservation potential.

2B.5.4 Survey Team Coordination Meetings. Coordination meetings should be held by the team members to discuss any considerations which interface between their fields and which may require additional on-the-job resolution. Tentative ratings of each building's conservation potential can be assigned without detailed analysis at this stage.

2B.6 Step 6. Selection of Buildings for Detailed Study.

2B.6.1 Evaluation and Ranking of Buildings. The following procedure is suggested:

a) Collate and organize all the material which has been collected.

b) Make a general evaluation of the physical and operational data collected from each building.

c) Compare building systems and data with known ECOs to establish level of potential for ECO feasibility. Indicate any additional, specific data requirements to be gathered during the in-depth survey, if building is selected for detailed investigation.

d) Rank the buildings according to their potential for energy conservation. Consider the order of magnitude of costs for implementing, and savings due to, these energy conservation measures.

2B.6.2 Recommendations. The energy study team should prepare detailed recommendations to contain:

a) Buildings with high energy conservation potential.

b) For all these buildings:
- Potential ECOs
- Estimate of the order of magnitude of potential annual savings in dollars and Btus
- Estimate of the order of magnitude of the cost of implementation.

c) Buildings which do not offer sufficient potential to warrant detail study, with justifications (e.g. too small, an energy conservation program already implemented, includes a special process which cannot be disturbed, etc.).

d) A list of buildings recommended for immediate detail studies.

e) Required records and metering. Whenever the energy study team considers that it would not be possible to evaluate significant ECOs without additional data, they should recommend necessary new or temporary metering to be installed and/or new records to be kept to obtain these data. In this way, the data will be available at the time the detail survey is carried out.

CHAPTER 3

BUILDING ENERGY APPRAISAL

SECTION A. INTRODUCTION

One of the most important components of a building energy study is the appraisal of the building's existing energy configuration.

This appraisal takes into account all energy entering the building, establishes the existing use of energy within the building, determines the energy leaving the building and identifies and selects for priority analysis those energy components which offer significant energy conservation opportunities (ECOs).

This HANDBOOK recommends two key tools for performing a building energy appraisal: development of a preliminary building energy flow and balance diagram and development and evaluation of the actual building energy indices against appropriate "standard" energy indices.

The procedure for building energy appraisal using these tools is presented in Section B of this Chapter. A step by step approach is summarized in Section C of this Chapter and schematically in Exhibit B in the Executive Summary. Section D presents the list of forms recommended for building energy appraisal and Section E the recommended method for manual calculations.

SECTION B. PROCEDURE FOR BUILDING ENERGY APPRAISAL

3B.1 General

The methodology recommended for building energy appraisal involves the following major steps:

- Review of Building Questionnaire
- Development of Preliminary Building Energy Flow and Balance Diagrams
- Establishing and Appraisal of Building Energy Indices
- Identification of Energy Conservation Opportunities (ECOs).

3B.2 Review of Building Questionnaire and ECO Checklist

This procedure assumes that a complete building selection procedure, as presented in Chapter 2, has been implemented, thus the Building Questionnaire and ECO Checklist are already available. All available information should be summarized for incorporation in the building energy flow and balance diagrams. Recommended forms for summarizing the quantitative data available are included as "Preliminary Appraisal Forms", Forms 3-1 Chapter 3 of Volume 2 of this HANDBOOK.

If the building in which the energy study is conducted has been selected by other procedures than those presented in Chapter 2, then this step should be preceded by all activities described under Steps 1,4 and 5 in Chapter 2, applied to the particular building under investigation. These activities include collection of available background data, filling out of the Building Questionnaire by the building staff, evaluation of the Building Questionnaire data by the energy study team, preparation of the ECO Checklist by the team and walk-through survey and answering the ECO Checklist by the team in cooperation with the building staff.

3B.3 Development of Preliminary Building Flow and Balance Diagrams.

3B.3.1 Definition. The building energy flow and balance diagram is a graphic representation of the primary energy entering, distributed and converted and/or consumed; of the secondary and/or

lower degree (generated through various stages of conversion) energy distributed and consumed; and of energy leaving the building.

Fig. 3-1 illustrates such an energy flow diagram, for energy entering a building from an outside source, with each line representing the distribution of annual Btu consumed to various conversion devices; further distribution to various types of equipment or terminal devices; and to the various points of energy disposal from the building.

3B.3.2 Purpose. The building energy flow and balance diagram establishes qualitative and, in a preliminary manner, quantitative relationships among various building energy systems. This can be employed to evaluate and reconcile specific portions of energy systems that relate to specific ECOs, with a fair assurance that their energy components are in a valid relationship to the whole. Once a valid order of magnitude for specific energy components is established in this manner, either calculation or computer simulation and analysis can be used to compare the "before" and "after" energy consumption of the overall building and of any given ECO.

3B.3.3 Types of Building Energy Flow Diagrams. Building energy flow diagrams may represent the instantaneous flow of energy through a building, or the totalized usage over a period of time. Most metered buildings employ instrumentation for billing purposes only, and often meter only the various forms of energy entering the building. Consequently, totalized monthly and annual usage hard data are frequently available, while instantaneous flow rates (demands and loads) are seldom available. It is recommended that preliminary building flow and balance diagrams be based on totalized consumption over the most recent one year period.

3B.3.4 Components of Energy Flow Diagrams. The energy nodes which make up a building energy flow diagram can usually be grouped within the following categories:

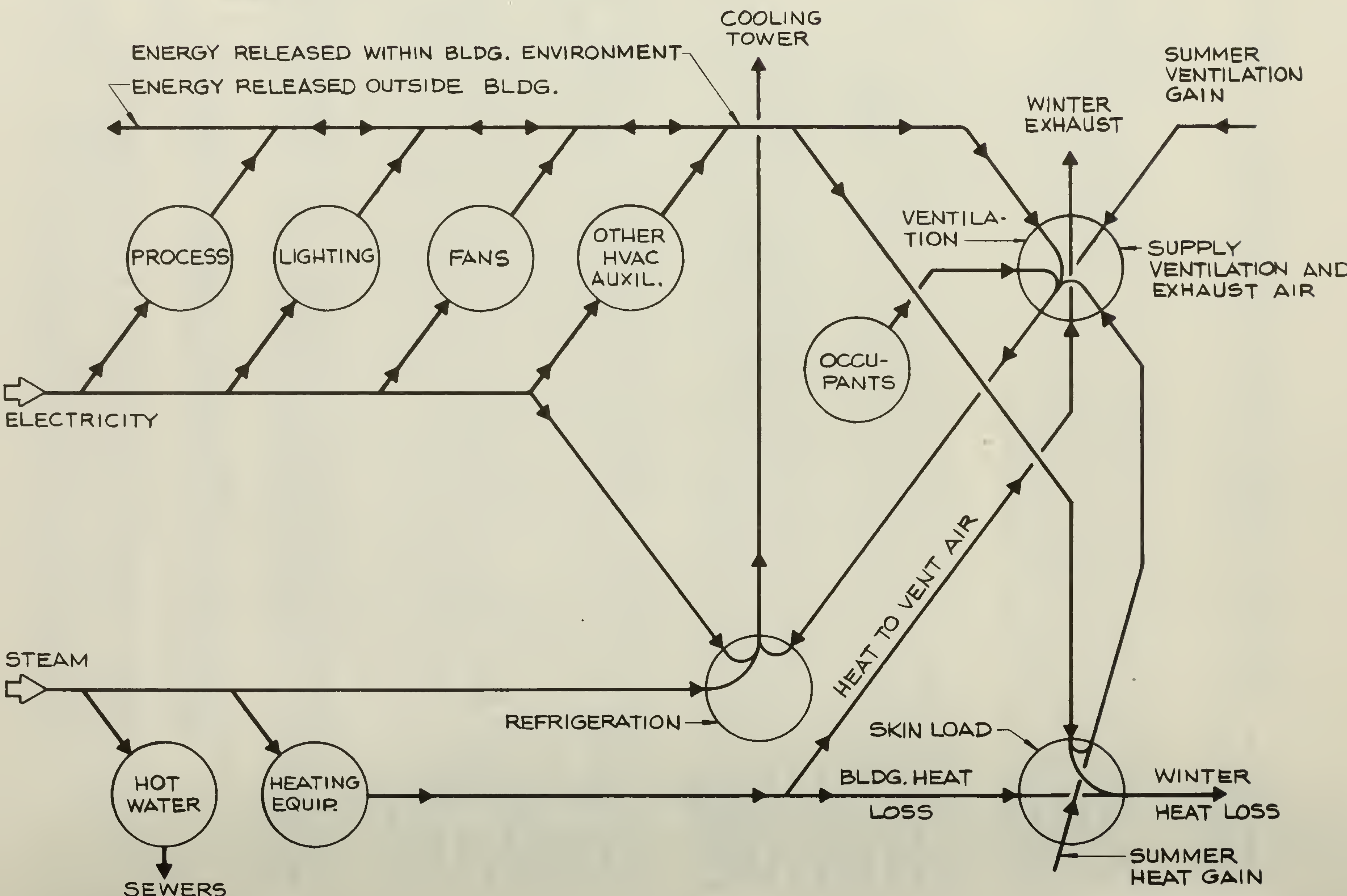
- Distribution of energy between entry point(s) of conversion (i.e. steam to turbine or absorption chillers)

- Primary conversion processes (i.e. refrigeration plant)

- Distribution of secondary energy systems (i.e. chilled water distribution to air handlers)

FIG. 3-1

PRELIMINARY BUILDING ENERGY FLOW DIAGRAM



- Secondary conversion processes (i.e. chilled water to conditioned air)

- Distribution of tertiary energy systems (i.e. conditioned air to terminal apparatus)

- Consumption (i.e. end-use at terminal device for lighting, heating, etc.)

- Energy leaving building (i.e. exhaust air from hoods, domestic hot water discharge, etc.).

The preliminary energy flow diagram need not pick up details of any component node. These details will be investigated during subsequent phases of the building energy survey and appraisal, when it appears that a particular node or node component presents an ECO.

The preliminary energy flow diagram should always show the total quantities of energy entering, consumed, and rejected, for a complete energy balance.

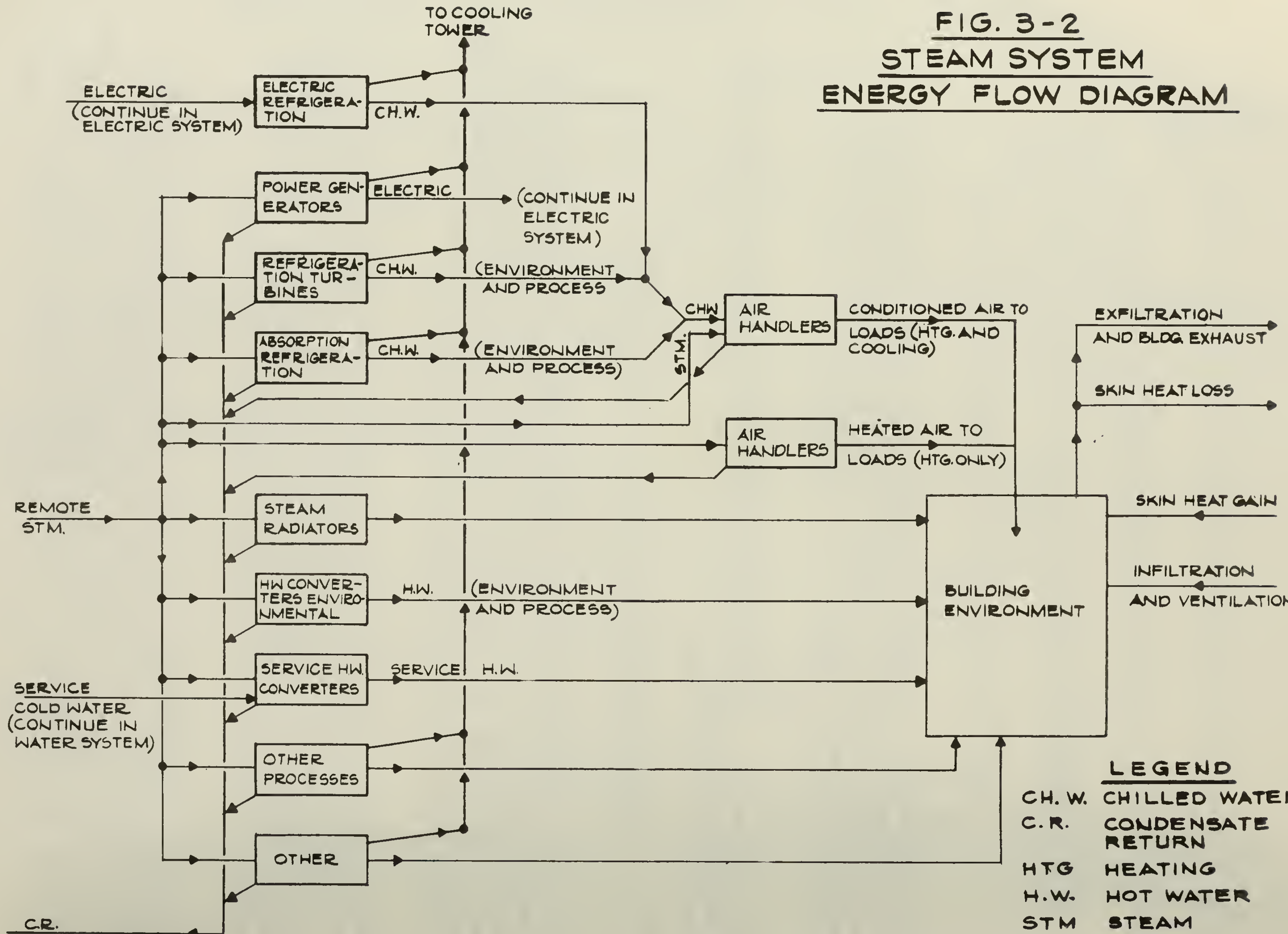
3B.3.5 <u>Preparation of Building Preliminary Energy Flow and Balance Diagrams.</u>

3B.3.5.1 <u>Background Data.</u> By combining available metered data with data from the Building Questionnaire, equipment characteristics, operating procedures and other data gathered during the survey and through discussions with facility and building personnel,it is some times possible to determine a totalized distribution of annual usage on a system by system basis and construct a building energy flow and balance diagram.

Whenever data from the Building Questionnaire and information from surveys and building management are not sufficient to develop a building energy flow and balance diagram, the actual building energy appraisal procedure presented in Subsection 3B.4 in this Chapter should be applied to determine approximate energy consumption within various energy nodes in the building.

3B.3.5.2 <u>Presentation.</u> The more complex a building's energy systems, the more difficult it is to show a meaningful energy balance of all energy systems on one flow sheet. The prime purpose can still be served if selected energy flows are depicted on separate diagrams, with cross-referencing of related energy systems or components. As an example, Figure 3-2 shows a system energy flow diagram for steam. This system flow diagram

FIG. 3-2
STEAM SYSTEM
ENERGY FLOW DIAGRAM



LEGEND

CH. W.	CHILLED WATER
C. R.	CONDENSATE RETURN
HTG	HEATING
H.W.	HOT WATER
STM	STEAM

also contains the flow of chilled water produced by absorption, steam turbine and electric motor driven chillers, so that the building's HVAC (or human comfort) energy balance can be analyzed as an entity. The same motor-driven chiller would also be shown on the electrical system energy flow diagram, cross referenced.

3B.4 Establishing Building Energy Indices

3B.4.1 Energy Index (EI) Concept. Quantitative analyses of the energy consumption in a building or in any of its energy nodes or node components can be advantageously pursued with the energy index (EI) concept. The energy index represents the total energy consumption within a building, or a building energy node or node component related to a significant building characteristic and to a specific time period.

The most commonly used time period for energy indices is one year and the most commonly used building characteristics are square feet of gross or air-conditioned floor area (resulting in energy indices expressed as Btu/SF/year). Other characteristics sometimes used are cubic feet of occupied spaces for residential and commercial buildings (resulting in EI expressed in Btu/CF/year) and pounds of products for industrial buildings (resulting in EI expressed in Btu/LB/year).

The selection of the most appropriate building characteristic for EI determination becomes extremely important when the energy performance of a building or its energy nodes is compared over different periods of operation, or under different projected or actual modes of operation, and when two different buildings' energy consumptions are compared. For example, valid comparison is possible when similar functional end results (i.e. HVAC temperature, humidity control and flexibility) are obtained in similarly constructed buildings with two different HVAC systems consuming different overall quantities of energy. Here, the common characteristics are the similarity of buildings and of functional requirements. The common characteristics of dissimilar buildings, in different locations or under different operating conditions is quite elusive, and requires cautious selection.

The energy indices in this HANDBOOK are expressed either in physical units, i.e. kwh of electricity per square foot per year, pounds of steam per square foot per year, etc.; or in Btu per square foot per year.

3B.4.2 Overall Building Energy Index (EI_b). As briefly presented in Chapter 2 of this HANDBOOK, such indices can be used for identification of buildings which offer high-probability for energy conservation. If the EI of a building is greatly (say 25% or more) in excess of a guideline EI for baseline or "standard" buildings of similar type and function, then the overall building energy index (EI_b) may be used as one of the criteria for selection of that building for detailed energy study.

Careful judgment must be used in the definition of building floor area (SF_b), if overall EI_b is to have any significance for comparison of different buildings and functions. This does not apply when comparing alternatives within the same building, as long as the same premise is used in all alternatives. For example, an office building with large ratios of storage or indoor garage area to gross area might appear to have a much lower EI_b than one without storage or garage, even though its heating and cooling indices might actually be higher. In such cases, the indices for various area functions should be separated for comparison. However, if the effect of any ECO in a given building is analyzed, all functions, no matter how diverse, can be lumped together because the differential accurately reflects the effect of the modifications.

The EI_b is of little value, however, as a tool in judging the performance of any individual energy node within a building. Therefore, the major thrust of the guidelines offered in this HANDBOOK is toward ECO identification through the use of nodal or system energy index (EI_n).

3B.4.3 Standard Building and Standard Nodal Energy Index. A national effort has been started through ASHRAE, FEA, ERDA, NBS and other governmental agencies as well as industry trade groups to collect statistics on actual building EI for the purpose of establishing norms or ranges of energy consumption for various building types and/or functions and processes.

The permutations and combinations of energy sensitive parameters that make up an EI_b, even for such relatively simple structures as office buildings, apartment houses and residences, are numerous, while those for industrial buildings are practically infinite. Consequently any attempt, particularly for industrials, to classify specific types as to firm parameters and EI is a most difficult task. ASHRAE's Industrial Energy Subcommitee of the Task Group on Energy Conservation is in the process of developing a concept for industrial buildings which is based

upon synthesizing overall EI by the summation of a broad variety of energy nodes, starting from a standard structure and standard human comfort requirements. The intent is to develop a tool which may permit the isolation of process or industrially oriented energy requirements, when separate metering between comfort energy and process energy requirements is not available. The basic premise of this methodology is employed in this HANDBOOK with respect to lab-office buildings, by establishing a reasonable standard office building EI_b measure against the actual EI_b of a lab-office building.

The techniques for nodal EI analysis are fairly well established and stem from a considerable bank of widely accepted experience figures and calculation procedures. For example the range of techniques for calculating seasonal or annual refrigeration requirements for comfort conditioning vary from the simplified "equivalent full load hours" calculations, through manual load duration curve analysis, to hour-by-hour load integration analysis by computer.

It is noted that the figures used in this HANDBOOK for the so-called standard building and standard nodal EI are intentionally selected to represent a high order of performance, or low EI, to better highlight any substantial differentials between the actual and the standard, thereby identifying the greatest number of possible ECOs.

3B.4.4 Adjustment from "Standard" to "Base" Building EI. The comparison of the EI of an actual building with the EI of a standard building should recognize those parameters which do not lend themselves to modifications. Parameters such as occupancy, building orientation, geographical location and climatic conditions cannot be changed in an actual existing building. The Base Building EI is an adjusted Standard Building EI reflecting:

- actual conditions for parameters which cannot be modified;
- ideal conditions for parameters which can be modified.

3B.4.5 Base Building and Base Nodal EI Appraisal Forms. The Base Building and Nodal EI Appraisal Forms (Forms 3-2 Chapter 3 of Volume 2 of this HANDBOOK) actually contain an abbreviated procedure for calculating a Base Building's design loads and EI_b for an approximate evaluation of the difference between the Actual EI_b and the Base EI_b.

Forms 3-2 provide quantitative data for relatively efficient EI with formulae for application to the actual conditions, and provision for calculations if required.

The calculated loads for cooling, heating and EI in Forms 3-2 lack several components affecting accuracy, but this will not significantly affect the ECO selections that stem from these appraisals. The loads are not intended to represent accurate heating, cooling and equipment loads, but approximate minimum loads for human comfort requirements. For example, the Base Building EI developed in Forms 3-2 ignore details of systems' design which might result in a greater or lower demand and usage of energy than the base requirements indicated, i.e. a terminal reheat system which creates artificial cooling and heating loads; credits during heating season from lighting, occupancy and solar heat gains; additional energy consumption resulting from excess summer dehumidification when coils extract more moisture than is required to maintain the design room relative humidity level.

Transmission load calculations in Forms 3-2 are adequate for quick determination of the impact of the skin or total building energy loads and usage. It is assumed that if a significant impact is found, a more accurate load study will be performed for the development of ECOs. Transmission factors for inside summer/winter design conditions and ventilation quantities were taken per ASHRAE 90-75. These values do not necessarily represent acceptable conditions in any particular facility. However, their use for the Base Building represents compliance with today's energy conservation ethic and permits evaluation, if desired, of the penalty for non-compliance. Outside design conditions, which cannot be manipulated, are taken for the actual climatic zone, at percentages that are compatible with ASHRAE 90-75.

Actual transmission areas, as well as occupancy are used assuming that the building's physical configuration and use are not readily changeable. This does not preclude consideration and evaluation of changing glass area by blanking a portion off, or scheduling occupancy in such a way as to reduce area usage and energy consumption.

All indices for heating (EI_h), cooling (EI_c), HVAC (EI_{hvac}), electrical (EI_e) and service hot water (EI_{hw}) are computed for equivalent Btu at both the building boundary condition (value of energy as used in actual building cycles) and at the source (value of the depletable fuel used to generate the energy consumed, whether the conversion occurs within or outside of the building boundaries).

Since Form 3-2 represents the synthesis of an overall human comfort EI_b from its component EI, there must be no duplication in the components and no process loads. For example, the electrical index, EI_e, must not include any allowance for electric refrigeration or electric heating energy, which would already be accounted for in EI_h, EI_c and EI_s. Process loads are intentionally omitted from all indices in Form 3-2.

Unlike refrigeration energy, which must not be duplicated in EI_e, lighting and fans which are components of cooling load in EI_c must appear again under EI_e. Lights and fans which are a heat gain for cooled areas do constitute double energy consumption parameters, one for dissipation by refrigeration and the other as direct consumers of electrical energy.

Service hot water EI_{hw}, similar to EI_c and EI_h, includes all energy requirements for normal human comfort, without regard to the type of energy which might provide it (i.e. fuel, electric, steam, etc.).

None of the Base Building energy indices include heat reclamation, whether or not such techniques are employed in the actual building. Specific ECO nodes will treat these as they arise in the analysis rather than by incorporation in the Base Building EI_b, to maintain the standardized concept of use for comparison with other Base Buildings.

It should be noted that the nodal energy indices are algebraically additive for obtaining the overall building energy index only when they share the same denominator (gross building floor area, for example).

3B.4.6 Actual Building and Actual Nodal EI Appraisal Forms (Forms 3-3). These forms are included in Chapter 3, Volume 2, of this HANDBOOK. They are intended to reflect the actual peak flow and annual consumption of all energy entering the building for the following purposes:

- Representation on the Energy Flow and Balance Diagram
- Comparison of actual EI components with those of the Base Building, for ECO identification
- Identification of unmetered components and approximation of their magnitude to establish a reconciliation with known totals and derive a rational order-of-magnitude for important components of energy.
- Evaluation of the need for computerized analysis of the building and its energy systems.

The raw data required for these forms are virtually identical to those which must be obtained for computer simulation of the energy systems in a building. Therefore the manual manipulation of data to synthesize the actual consumption has been organized in a manner which will facilitate use by either computers or calculators.

It must be assumed that the analyst using these forms is familiar with the basics of heating/cooling load calculations and will make necessary adjustments to the guidelines shown, as dictated by actual building conditions.

a) Actual Building Cooling Output (EI_c Output).

This is an approximate simulation of the actual cooling conditions conducted in a manner similar to that described for the Base Building, but using the actual known parameters of indoor design conditions transmission factors, lighting, fans, process and ventilation loads. Conversion from peak loads to annual consumption is made on the basis of equivalent full load (EFL) hours for each component with its own load profile. Compilation of load profiles for significant energy components is necessary for both manual and computerized analysis, and is approximate for both on many components. Computerized skin heat gains and losses are usually faster and more accurate than manual calculations.

b) Cooling Load and Energy Input (EI_c Input).

The procedures indicated in Forms 3-3 are the means by which calculated loads and energy consumption may be brought in line with estimated or metered figures, so that the individual load components can be isolated and analyzed. Reconciliations must be made from as many different bases as are available from survey data (i.e. steam + electric refrigeration must be equal to ton-hours equivalent for these machines as shown in the tabular breakdowns in this section of Form 3-3, as well as in the breakdowns of any steam and electric meters which might monitor the equipment involved). All quantities are expected to be consistent with reported or metered records of installed equipment.

c) <u>Heating Load and Energy Output and Input</u> (EI_h)

These calculations are conducted in much the same manner as for cooling. Although credits for internal gains in perimeter areas with exposed skin are not shown, they may be calculated manually when building systems are designed and operated to take advantage of such credits. For example, a perimeter area heated with hot water radiation, which is arbitrarily scheduled to compensate for 100% of skin heat loss, does not benefit from either indoor heat gains or solar gains (unless it is in an exposure with zoned, solar compensated scheduling and no moving shadows from neighboring structures). Similarly, for a computerized analysis to be accurate in this respect, its program must be capable of recognizing such factors. Some programs take such internal gain credits whether or not the energy gains actually occur.

d) <u>Actual Building Service Hot Water Consumption</u> (EI_{hw})

Procedures and guidelines are given for computation and reconciliation directly in Form 3-3.

e) <u>Actual Net Process Energy Consumption</u> (EI_p)

The intent of this section in Form 3-3 is to flag only those process energy quantities which can be readily identified and quantified and do not appear in the other indices. If they can be identified in this manner, they should be deleted from the other indices.

f) <u>Actual Net Building Electrical Energy Consumption</u> (EI_e)

This section in Form 3-3 identifies previously accounted for electrical consumption and subtracts it from the overall metered consumption to derive the net consumption for further pertinent breakdown, similar to that for the Base Building, but including remaining process energy. The deleted items should be added back for the total electrical consumption, used in establishing total EI_e and in the energy flow and balance diagram.

3B.4.7 Building Energy Indices Synthesis for Building Energy Flow Diagram (Form 3-4). Energy indices may be used to construct the building energy flow and balance diagram. Forms 3-4 in Chapter 3 of Volume 2 of this HANDBOOK have been prepared for this purpose. Forms 3-4 also assist in an overall reconciliation of all energy system quantities in Forms 3-3 with actual available data.

Forms 3-4 take the analyst through the complete path of each energy system, by keying the incoming and outgoing type and quantity of energy on each sheet to previous or subsequent flow sheets. Each tabulation in Forms 3-4 takes a single energy node through at least one conversion or degradation process. (Energy degradation without conversion is illustrated by high pressure to low pressure steam through a non-condensing turbine; or temperature drop of hot water through a heat exchanger). The tabulations are intended to show the energy flow of each stream through each type of process change. Similar processes may be grouped together.

Some values are derived from calculations in Forms 3-2 and 3-3 directly; others from new calculations, but they must all reconcile with one another and with the totals that are metered or calculated for each energy stream (i.e. electricity, steam).

3B.5 ECO Identification

3B.5.1 Direct Use of Preliminary Energy Flow and Balance Diagrams. The preliminary energy flow and balance diagram could be used as a basis for possible ECO identification because it highlights nodes of high energy consumption.

The criterion of high energy consumption should be used with judgment and in combination with other criteria before detailed survey and analysis of nodes or node components are performed. Some of the other criteria to be considered are:

- average consumption rate or energy index;
- adaptability of the equipment or operational procedures to modifications, and
- extent of previous energy conservation measures for the node involved.

The direct use of the preliminary energy flow and balance diagram for ECO identification should be considered only when time limitation does not allow for development of building energy indices and appraisal of actual vs. base building indices.

3B.5.2 Appraisal of Actual vs. Base Building Indices. The intent of the appraisal is to identify the energy nodes which are most significant and to provide guidelines for estimating the feasibility of their modification, when adequate information is available. It is often possible to accomplish this without detailed examination of the nodal breakdowns.

Techniques include numerical comparison of the Actual Building and Base Building energy indices, and comparison with other guidelines or norms, as indicated below (Refer to Forms 3-2 & 3-3):

a) Skin Summary and Appraisal

A comparison of base building and actual building transmission EI should be performed for walls (EI_w), roof (EI_r), glass(EI_g) and total skin transmission ($EI_t = EI_w + EI_r + EI_g$).

It is important to know the order of magnitude of solar loads so that the ratio of skin transmission to total load can be studied in the proper perspective. Since the parameters which affect solar loading (Btuh/SF_b) in any given structure are many and varied (i.e. exposure, solar isolation, percentage and shading factor of glass, "U" factor of glass walls and floor area, etc.) it is impossible to refer to "typical" loading, but it is safe to say that a reasonable range of solar loading for multi-story office buildings (2 or more stories), built circa 1954 to 1971, would be from 50 to 200% of the transmission loading. Transmission loading in the same context would be in the range of 2 to 8 Btuh/SF_b, while total building loadings for summer, including solar, would range from 22 to 40 Btuh/SF_b.

The ratio between actual skin EI_t and actual building EI_b and the ratio between base skin EI_t and actual skin EI_t should also be calculated. If the former ratio is more than 15% and the latter ratio is less than 50%, it is an indication that the magnitude of skin modification savings may have priority potential and may justify the time and cost of computer refinement. Weigh together with other ECOs and against cost guidelines in Chapter 4, Section E, before resolving computer issue.

b) Occupancy Appraisal.

The Base Building occupancy was initially assumed at the actual level for cooled areas. Normal occupancy in an office building varies from 75 SF/occupant (densely populated) to 150 SF/occupant (sparsely populated). This is equivalent to 5.3 and 2.6

Btuh/SF respectively for the 400 Btu/occupant of sensible heat and latent heat combined. These loadings and their duration are not normally subject to variation. Benefits of change of occupancy, when possible to effect, derive from the potential of indirect savings, rather than any direct load reduction. For example, shifting of personnel to extract benefit from evacuated spaces might permit shut-off of lights, HVAC systems or other services, even though the occupancy total itself is not changed.

Occupancy densities above 150 SF/occupant might indicate the possibility of considering such steps, if they can be implemented without harm to the purpose, function or process for which the personnel are present.

c) Lighting and Receptacle Appraisal.

High local or overall lighting and receptacle load densities indicate the possibility of ECOs. Refer to Appendix 2 for definitions and usual values of watts per square foot, demand and load factors in various type buildings and building areas. Appendix 2 also contains typical selection guidelines and representative coincidence factors. Overall lighting densities (watts/SF of gross area) can be misleading, especially if there is a large ratio of non-functional to gross area. There is a twofold benefit to lighting reductions in cooled spaces (lighting + refrigeration energy). Therefore, this appraisal should consider the electrical and the cooling energy indices (EI_c and EI_e).

Heated spaces may or may not receive heating credits from lighting, depending upon heating system design, configuration and operation.

d) Ventilation Appraisal.

Actual ventilation requirements may be governed by any one of the following factors:

- Local, municipal, safety, health or other jurisdictional codes;
- Arbitrary, rather than current good practice;
- Special process exhaust system requirements.

Any excess of ventilation above that of the Base Building (0.075 CFM/SF) represents a high potential energy saving. This can be illustrated by the following tabulation based upon each 0.1 CFM/SF increase,

showing the peak loads for summer and winter in a northerly climate.

	ROOM DESIGN DB/% RH	OUTDOOR DB/WB	BTUH/SF/0.1 CFM SH	LH	TOTAL
Summer	78/60	95/75	1.84	0.82	2.66
Summer	75/50	95/75	2.16	2.32	4.48
Winter	72	0	7.76	-	7.76

Some of the outdated criteria upon which many existing building designs were based have resulted in present day facilities that frequently lend themselves to easily implementable ECOs involving ventilation. Examples of such criteria are:

- Minimum 25% ratio of outside/supply air. With even low supply air rates of 1.0 CFM/SF, this corresponds to 0.25 CFM/SF which results in 2.5 times the above tabulated loads.

- Minimum of 2 air changes per hour. With a 10'-0" ceiling height this corresponds to: 2 a/c x 10 ft./ 60 = 0.33 CFM/SF.

- Allowance of 20 CFM/occupant, which corresponds to 0.26 CFM/SF @ 75 SF occupant and 0.13 CFM/SF @ 150 SF/occupant. Current ASHRAE Standards recognize that, in many circumstances, 5 CFM/occupant is acceptable.

The results of such obsolete criteria compared with the other component Btuh/SF loads reveal that ventilation, even in moderate quantities 0.15 CFM/SF is one of the larger components of the heating and cooling loads, which ranges in typical office buildings from 22 to 40 Btuh/SF during summer and from 20 to 35 Btuh/SF during winter design conditions. Ventilation at 0.25 CFM/SF is approximately 25% of the total summer load and 60% of the total winter load.

Any building with more than 0.1 CFM of ventilation air per SF should be examined very carefully for ECOs in this area.

e) <u>Fan Heat Gain Appraisal</u>

If fan hp for a system's supply fan is greater than 1/3 hp per 1000 CFM handled, it is an indication of static pressures higher than 1½ w.g. Although duct sizes cannot be readily changed to reduce pressure requirements, there are a number of techniques described in Chapter 5 which can be effective

in reducing fan hp. Like lighting, this is a double benefit since both refrigeration and fan electrical energy may be saved.

f) Process Appraisal.

Any substantial difference between the actual and base figures in either EI_c, EI_{hw} or EI_e is the result of one or more of the following characteristics:

- Systems which have been designed for greater energy consumption than is required for base loads.
- Actual loads or EFL hours for human comfort in excess of those indicated for the base building (resulting from more intensive standards or longer periods of occupancy).
- Process loads or criteria that are in excess of the actual buildings human comfort requirements.

The breakdown of these quantities without separate process system meters is elusive, involving a high degree of judgment and experience. Some guidelines may be given which will help to keep the energy components in some perspective. Since unmetered process energy evaluation is a subtractive process, this guideline appraisal technique, together with more lengthy manual or computerized calculations may be necessary.

Specific knowledge of the magnitude of process load and energy consumption, separate from those of human comfort is not always necessary for effective ECO analysis. It is usually essential when there is a distinct separation of system, node or function, but is sometimes immaterial when a combined human comfort and process load are served. For example, if large ventilation quantities are mandated by process, but simultaneously serve both comfort and process, then reduction of total ventilation (if acceptable to the process) does not require a clear separation of process and comfort systems.

(1) Refrigeration & Heating. Design summer loads for office buildings ranging from 22 to 40 Btuh/SF correspond to 150 to 300 SF/Ton respectively. Any refrigeration in excess of this range in an office building

would most likely represent a process load, but an accurate determination of how much of the excess over base building requirements can be charged to process and how much to more intensive human comfort requirements must evolve from an individual nodal analysis of the parameters involved.

Similar considerations apply to the heating cycle for isolation of process loads.

(2) Service Hot Water. Any service hot water requirements in excess of that for base building may be taken as process oriented unless some of the excess can be specifically identified for human comfort (domestic hot water).

(3) Electricity. Process loads may be isolated by the techniques indicated in Form 3-3.

A listing of high electrical energy using equipment together with annual hours of use as determined by operation records or by knowledge of process management personnel will assist in accounting for a major proportion of electrical consumption for process loads. Energy for smaller loads can be approximated from connected ratings and experience demand factors.

An example of filled out Forms 3-3 and 3-4 is included in paragraph D of Appendix 3.

SECTION C. STEP BY STEP PROCEDURE FOR BUILDING ENERGY APPRAISAL

Step 1. Obtain and review basic data, Building Questionnaire, meter readings, drawings, etc.

Step 2. Develop Preliminary Energy Flow Diagram

Step 3. Quantify to the extent possible the energy nodes in the Energy Flow Diagram from:

a) Meter readings
b) Information provided by Building Questionnaire
c) Other record data

Step 4. Perform actual building energy appraisal. Develop total energy consumption by nodes using actual conditions for all parameters (equipment capacities, load profiles, occupancy data, physical characteristics, etc.). Develop actual building energy indices.

Step 5. Reconcile figures developed with known totals from actual meter readings and other hard data. Identify reasons for discrepancies and recalculate building energy flows as necessary.

Step 6. Complete Energy Flow and Balance Diagram

Step 7. Develop base building energy indices based on:

a) Actual conditions for parameters which cannot be modified.
b) Ideal conditions for other parameters.

Step 8. Identify:

a) Energy systems with likely ECOs based on comparison of "base" to "actual" indices.
b) Specific ECOs based on knowledge of the building and its systems, developed during the foregoing process.

SECTION D. LIST OF FORMS FOR BUILDING ENERGY APPRAISAL

The following forms for building energy appraisal are included in Chapter 3 of Volume 2 of this HANDBOOK.

FORMS 3-1	Preliminary Energy Appraisal Forms
FORMS 3-2	Base Building Energy Appraisal Forms
FORMS 3-3	Actual Building Energy Appraisal Forms
FORMS 3-4	Energy Flow Diagram Synthesis Forms

SECTION E. MODIFIED BIN METHOD FOR MANUAL ENERGY CALCULATIONS

4F.1 General. This HANDBOOK contains recommendations for calculation procedures for those building energy studies which do not justify a computerized analysis. These procedures are a modified version of the Bin Method presented in ASHRAE's 1973 systems Guide(Reference 1) and are referred to in this HANDBOOK as the Modified Bin Method.

4F.2 Purpose. The purpose of the calculations is to determine annual energy consumptions in various component energy systems whenever detailed metering or records are not available.

4F.3 Description of the Modified Bin Method. The Modified Bin Method uses both the equivalent full load (EFL) hours and the Bin Method concepts for establishing annual energy requirements in various energy nodes.

By definition, the EFL hours is a guideline figure which by multiplication with the peak load in one energy node provides the total energy consumption in that node. For example, annual peak refrigeration tons x EFL hours = total refrigeration ton-hours per year.

The Bin Method (Reference 1, Pg. 43.13) tabulates the heat gain or loss of an entire building as a function of ambient temperature and applies each load to the number of hours per year when that temperature occurred, usually in 5 or 10 degree increments. The consumption for each temperature range or bin is the average load in that bin x hours of occurrence. The annual load is the sum of all these consumptions at each bin.

The shortcomings observed in Ref (1) for the Bin and EFL Hour Methods are eliminated with the technique developed in this HANDBOOK. The reasons are presented below:

- When the Bin Method is used as in Reference (1) to project annual consumption of a proposed new facility, many factors are unknown and there is no point of reference. However, applied to existing buildings for simulation of actual consumption, the calculations can usually be reconciled with an actual reference.

- The Bin Method as described in Reference (1) is applied to total building heating and cooling loads, therefore it lacks the ability to track load profiles of component loads. The concept proposed here applies the Bin hourly occurrences only to those load components which are sensitive to weather, considering time, temperature and coincident wet bulb slots that relate to each pertinent energy component(i.e. EFL_h to heating transmission losses and winter ventilation; EFL_c to cooling transmission and sensible ventilation; and wet bulb EFL_v to latent ventilation load).

- For components not sensitive to weather, appropriate EFL hours are used with the best available knowledge of actual load profiles, operating hours, and system specifics.

This separation of each component load, particularly for "before" and "after" analysis of an ECO dealing with that energy component alone, permits simplification of studies and numerous variations of the ECO, without recalculation of the entire Bin tabulation, or an entire computer run for the building.

The application of the Modified Bin Method to an actual building for transforming climatic hourly occurrences into usable and rational EFL hours is presented in Appendix 3.

CHAPTER 4

SURVEY AND APPRAISAL OF BUILDING ENERGY CONSERVATION OPPORTUNITIES (ECOs)

SECTION A. PURPOSE

Chapter 4 presents the methodology for survey and technical and economic appraisal of the ECOs identified within the building energy appraisal described in Chapter 3. The ECO survey and appraisal methodology includes additional data collection for the ECOs under investigation, technical feasibility evaluation for these ECOs and economic evaluation and ranking of the technically feasible ECOs.

Sections B, C and D in Chapter 4 contain respectively the concepts, a step-by-step procedure and a listing of the recommended forms for ECO survey and appraisal. A schematic presentation of the recommended procedure is also included in Exhibit C in the EXECUTIVE SUMMARY.

Evaluation of building ECOs can be performed manually or by computer. Section E in Chapter 4 presents the major advantages and disadvantages of these two calculation modes, indicates general conditions under which a computerized approach is justified and describes the major components of a typical computer application.

SECTION B. METHODOLOGY

The methodology for building ECO survey and appraisal should include the following activities:

- Preliminary evaluation of the ECO prospects identified
- Additional data gathering through ECO oriented in-dept surveys.
- Technical evaluation of each ECO.
- Economic evaluation and ranking of the technically feasible ECOs.

4B.1 Preliminary Evaluation of ECOs. It is sometimes possibl to conduct a fairly valid feasibility study for some of the prospective ECOs without any survey. It is advisable to do thi prior to the in-depth surveys and even to run such studies as far as possible for ECOs with incomplete data. This will serve to expose missing data necessary for specific ECO evaluation and help ensure efficient collection of these data during the in-depth survey.

4B.2 ECO Oriented In-Depth Energy Survey.

4B.2.1 In-Depth Survey Forms. Chapter 4 in Volume 2 of this HANDBOOK contains a set of basic ECO oriented in-depth survey forms (Forms 4-1).

These survey forms serve as a checklist of data which should be collected to permit in-depth analysis of those nodes or node components which lend themselves to technical or procedural modifications resulting in possible ECOs.

a. Scope. Although some energy system aspects are common to any structure, regardless of physical configuration, function and system design, it is appropriate to consider many ECOs as they apply to specific types of buildings.

   It is the intent of this HANDBOOK to cover primarily the specific characteristics of laboratory-office type buildings. Therefore, the in-depth survey forms as well as the ECOs contained in this HANDBOOK reflect

mainly the characteristics of laboratory office type buildings.

b. Schedule. Since specific ECOs differ from building to building, the classification of the in-depth survey forms in this HANDBOOK has been based upon separation of systems which convert, distribute, consume, and reject various energy types. This classification, which allows the isolation of major energy nodes, is also used for presentation of major building ECOs and is included at the beginning of Chapter 5 in Volume 1.

4B.2.2 Selection and Refinement of In-Depth Survey Forms. The in-depth survey forms included in this HANDBOOK cover the most common aspects relating to ECOs in laboratory-office type buildings.

Not all in-depth survey form categories will be required for each building investigated. Only those categories relating to specific ECOs identified should be selected.

The in-depth energy forms should be adapted to best reflect the specific conditions in each building. In addition to information in the Building Questionnaire and data gathered during the walk through survey, the ECO Related Questions included in Appendix 1 should be used for the refinement of the in-depth survey forms.

4B.2.3 In-Depth Survey Preparation. It is recommended that an agenda and schedule of survey activities be discussed with facility personnel.

The survey team should specify those data requirements which might require some time for accumulation by the building staff.

Prior to the survey, a meeting should be held with building operating and process personnel who are closely associated with or affected by proposed ECO modifications. The discussions should cover the intent and practicality of execution and operation of ECOs and are expected to result in confirmation of the validity of certain ECOs, raising of additional questions to be answered, or sound arguments which might

mandate immediate elimination of some ECOs. Such eliminations can save all concerned considerable time and effort which can be more productively applied to other ECOs.

4B.2.4 In-Depth Survey. Using the adapted in-depth survey forms, the actual data gathering should be performed in close cooperation with pertinent building staff. The survey should be conducted with the intent to collect missing data for ECO studies and to keep a sharp lookout for any good prospects that may have been missed.

4B.3 Technical Appraisal of ECOs. The technical feasibility of each ECO should be established based on survey data, general knowledge about the building, discussions with building operating personnel and specific ECO characteristics. These latter characteristics are presented under each ECO in Chapter 5, Volume 1 of this HANDBOOK.

4B.4 Economic Appraisal of ECOs.

4B.4.1 General. The economic appraisal of ECOs should be completed in accordance with ERDA standard procedures using life-cycle costing. The procedures are fully explained in other ERDA publications including "Life Cycle Costing Emphasizing Energy Conservation" ERDA-76/130 and "Interim Life-Cycle Costing Guidelines" (ERDAM 6301 of May 4, 1976) to which the reader may refer.

4B.4.2 Measures for Economic Evaluation of ECOs. The recommended measures for economic evaluation of ECOs are:

- savings/investment ratio
- discounted payback period
- Btu savings/investment dollar
- capital investment

a. Savings/Investment Ratio (SIR). The SIR is considered to be the best measure of overall expenditure performance. The SIR is obtained by dividing the present value of net future ECO cost savings by the present value of the investment necessary to realize these savings. A savings/investment ratio which is greater

than 1.0 indicates that the proposed investment is cost-effective and that the ECO evaluated will return all capital funds at a greater than the discount rate. Accordingly, the greater the value of the SIR, the more cost-effective the investment opportunity.

b. Discounted Payback Period. The payback period is one of the oldest and most widely used measures of investment performance, but it is not as reliable a measure of overall performance as is the SIR because it fails to consider the financial returns of a project after it has paid out. There are two types of payback: simple and discounted. The simple payback period is the length of time required for the accumulative savings from an ECO to equal the investment without considering the time value of money (discount rate). The discounted payback period considers the time value of money in determining the accumulative savings. The use of the discounted payback period is recommended. This measurement distinguishes between SIR's of similar value and assists in determining the attractiveness of an investment without extensive analysis.

c. Btu Savings/Investment Dollar. The purpose of initiating energy conservation programs throughout ERDA is to conserve energy. For this reason, in addition to the strict measures of financial performance, a measurement of the number of Btus saved per investment dollar should also be made.

The Btu savings/investment dollar is the ratio of the average annual amount of Btu savings divided by the average annual present value of the investment, the latter representing the net present value of the investment divided by its economic life.

The Btu savings/investment dollar puts into a better perspective the ECOs at facilities with low energy costs. Similar ECOs saving the same number of Btus will not yield equivalent savings/investment ratios at different sites because of differences in the cost of energy. From the standpoint of nationwide energy conservation, the Btu savings/investment dollar is considered to be a valid indicator of investment performance. Source Btus should be used in calculating Btu savings.

d. Capital Investment. This is the last recommended measure for ECO evaluation. In most applications, the funds available for energy consrvation are limited. The capital investment for a certain ECO with good savings/investment ratio, discounted payback period and Btu savings/investment dollar may exceed the available funds or may consume so much of these funds as to preclude implementation of other ECOs with better combined energy conservation results.

4B.4.3 Economic Evaluation of Individual ECOs. Each technically feasible ECO should be evaluated using the measures described above. All ECOs with an SIR less than 1 should be eliminated from further consideration.

Complete definitions and interpretation of the economic terms, as well as annuity and other financial charts and tables and detailed presentations of the calculations involved are contained in ERDA 76/130, referenced on page 4-4.

Form 4-2, included in Chapter 4, Volume 2 of this HANDBOOK will assist in the presentation of the economic data relating to each ECO.

4B.4.4 Ranking of ECOs. Following individual economic appraisal, the ECOs should be ranked based on SIRs. The ECO with the highest SIR will be ranked number 1. Form 4-3 in Chapter 4 of Volume 2 is designed for this purpose.

After the first ranking, the savings and capital costs of each ECO should be recalculated considering the effect of implementing the highest ranking ECO on the energy balance. ECOs should then be reranked based on the recalculated SIRs. This procedure may result in elimination of some lower ranking ECOs. This is due to the fact that, by implementing one ECO, some other ECOs may no longer result in sufficiently high energy and cost savings to be economically justified. The recalculated SIR of such ECOs becomes less than 1, and the ECOs involved should be eliminated from further consideration.

The above reranking procedure shall be repeated assuming that the second highest ranking ECO has also been implemented. After reranking and elimination of ECOs with SIR less than 1, the procedure shall be applied again for the third, fourth, etc. ranking ECO, until all compatible ECOs are quantified and ranked.

SECTION C. STEP BY STEP PROCEDURE FOR ECO APPRAISAL

Step 1 Preliminary ECO Appraisal. Based on available information, evaluate technical feasibility of ECOs. Eliminate those ECOs which do not seem feasible and define to the extent possible the additional information required for evaluation of other ECOs.

Step 2 In-Depth Survey Forms Refinement. From among Forms 4-1 in Chapter 4, Volume 2, select those form categories which are pertinent to the ECOs to be investigated. Adapt the selected forms and prepare additional survey forms, if necessary to suit local conditions. Use available knowledge about the building and its energy systems as basic data, and Appendix 1 - ECO Related Questions - as a guide for additional data requirements.

Step 3 ECO Oriented In-Depth Survey. Prior to survey, submit to the building staff a list of necessary information which requires some time for accumulation and hold a meeting to discuss tentative ECOs. Collect additional data necessary to define the ECOs under investigation. Use refined In-Depth Survey Forms (Forms 4-1, as adapted).

Step 4 Technical Appraisal of ECOs. Evaluate the feasibility of each ECO, using the ECO presentations in Chapter 5, Volume 1 as a guide.

Step 5 Economic Appraisal of ECOs. Prepare estimates of savings/investment ratio (SIR), discounted payback period, capital cost and Btu savings/investment dollar. Eliminate ECOs which are not economically justified. Use Form 4-2, Chapter 4, Volume 2 in this HANDBOOK. Follow methodology presented in Life Cycle Costing Emphasizing Energy Conservation, ERDA-76/130.

Step 6 ECO Ranking. Rank all compatible ECOs based on SIR. Use Form 4-3, Chapter 4, Volume 2 and follow guidelines in ERDA-76/130.

Step 7 Refined Energy Flow and Balance Diagram. (Optional). Prepare refined diagram for existing energy conditions based on detailed data collected during the in-depth survey. Prepare diagram reflecting future energy flow and balance, considering the effects of the ECOs recommended for implementation.

SECTION D. LIST OF FORMS

SECTION E. USE OF COMPUTERS IN BUILDING ENERGY AND ECO APPRAISAL

4E.1 General. A number of computer programs have been developed to assist in building energy studies and can be used to complete many of the steps described in the foregoing sections. Such programs are listed in Chapter 5 under ECO M-4. These programs are designed to simulate the building energy systems using refined input such as hour by hour weather tapes. They are largely based on energy systems found in typical office buildings. To evaluate the impact of an ECO, the program is first run without the ECO, and then with the ECO; the energy saved is the difference in energy requirements calculated in the two runs. This allows the program to be re-run with different combinations of interrelated ECOs until the energy savings are maximized.

The justification for a computerized analysis varies considerably depending on building specifics. Some considerations and criteria for evaluating the feasibility of a computerized energy analysis for a given building are presented below.

4E.2 Considerations Relating to Computer vs. Manual Calculations.

4E.2.1 Cost. Arrangements for a computerized analysis may vary considerably. At one extreme, a complete analysis, including the collection and preparation of input data, testing and running of program may be subcontracted. At the other, all data may be prepared in-house and an in-houe program be used. The following factors affect the relative costs, whatever arrangements are made:

a. Complexity of Building Energy Systems and Number of ECOs to be Evaluated. The initial setting up and first run of the computer program may be more costly than the manual calculations. However, re-runs to test different ECOs and combinations of ECOs, especially in a complex energy system, will probably be less expensive on computer than as manual calculations.

b. The Adaptability of Available Programs. Most computer programs have been prepared for standard office buildings. ERDA buildings are largely non-standard. Additional work to adapt the program to the building being studied increases the study cost.

c. Input Data. Computer programs may require more refined input data. The additional cost of collecting these data must be considered.

d. Time. If an off-site computer is used, delays caused by mailing and processing computerized calculations may lead to lower productivity of the survey team and hence increased costs. These can be offset by using a local terminal where available.

4E.2.2 Accuracy. A computer program using hour by hour weather tapes and other refined input data can produce a higher level of accuracy than manual calculations.

a. Degree of Accuracy Required. Accurate output is only justified to the extent that it will lead to the correct selection of building ECOs to be implemented. It is not so much the absolute level of accuracy in many calculations for ECO analysis which is important, but the accuracy of the differential between the "before" and "after" situations. So long as any error in the component consumption is consistent for both "before" and "after", and is within reasonable values based upon good judgment and experience; and so long as the effect of the modification allows for these consistent "errors", then the accuracy of the differential, which is the major purpose of the calculations, can be expected to be reasonably valid.

b. Accuracy of Baseline Data. ECOs requiring more precise analysis for reasons of system complexity can be no more accurately rendered by a computer than the order of accuracy and detail of the input data used for system simulation. Some energy characteristics can be modelled much more precisely by computer than by manual calculation (i.e. skin heat gains and losses based upon hour by hour weather records tapes). Others, either because of the diversity of load magnitude and load factor, the sheer number of loads, or the lack of precise load profile data, must be so simplified that the computation performed in the computer can be conveniently duplicated by manual calculation (i.e. lighting profiles for interior areas with 2 or 3 load steps and 3 typical days per year).

c. Accuracy and Variety of Computer Routines Available. The cost and time span for turn-around of computer runs can be justified if the available accuracy of specific program routine tracks the accuracy required for valid simulation of the selected ECOs.

In addition, the number of routines available for specific ECO manipulaton must have adequate routine option flexibility to permit before and after comparisons of each ECO. A major problem of all building energy analysis problems used today is the lack of availability of features or options which might be required in many conservation analysis, particularly for industrial buildings and process applications. Such things as hybrid HVAC systems, heat transfer or air flow from one thermal block to another; energy conversion plants such as those for heating, cooling and selective energy with even moderately sophisticated sequencing; and unconventional energy sources are either not programmed or have inadequate sophistication.

4E.2.3 Importance of Systems Which Can Be Easily Modelled on Computer in Overall Building Energy. This HANDBOOK addresses mainly laboratory-office type buildings. A laboratory-office building resembles an office building in many respects (i.e. structure, occupancy, lighting), and the laboratory process loads may be considered as the difference between normally expected office building loads and actual laboratory-office building loads. However certain parameters, such as extremely high quantities of ventilation and exhaust air in a laboratory-office building, call for analysis and ECO treatment which can be totally different from considerations applying to office buildings.

While the skin transmission and solar loads in an office building may represent a substantial portion of annual energy requirements, indicating possible skin modification ECOs and justifying accurate weather tape computer analysis, the identical skin configuration in a laboratory-office building might represent only a minor portion of total energy consumption. The need for hour-by-hour computer analysis of segments of total energy consumption which are of minor significance should be examined critically, especially when the internal load profiles fed to a computer are approximate. The greater the number and importance of special purpose internal and process loads and/or the lower the accuracy of these internal load profiles, the less justification there might be for employing computer analysis for the entire building.

Conversely, if the magnitude of energy consumption in systems for which sophisticated program routines requiring accurate data is large in relation to those which are simplified, a computerized building energy analysis may be justified.

4E.3 Preliminary Selection Criteria. Following are some general criteria recommended for the decision making process involving computerized vs. manual building energy calculations. These general criteria must be adapted to specific local conditions.

Usually, a computerized building energy study may be economically justified when the building under consideration has:

- a gross floor area of at least 60,000 sq. ft;
- an average annual utility bill in excess of $100,000;
- complex energy systems that can be readily blocked out;
- good metering and records for energy systems;
- a large number of ECOs to be investigated;

and especially when:

- the computer routines available match those building energy systems offering most significant ECOs;
- high level of accuracy for energy calculations is required;
- the time period available for completion of the building energy study is at least three months;
- the computer and/or computer specialists are available in-house or nearby;
- personnel are not available for manual operations.

4E.4 Computer Application. Typical computer programs provide for:

- hour-by-hour calculation of the annual energy consumption of various types of air-side systems and mechanical plants;
- application of local utility rate schedules to these demands and consumptions; and
- combining these costs with other owning and operating costs for year-by-year cashflow projections.

Each major step in a complete energy system analysis may be handled by a different program, thereby permitting the evaluation of the results of one part before finalizing inputs and proceeding with the next part.

Representative programs in a library include:

a. Energy Requirements Estimate. A program to calculate hour-by-hour thermal and electrical loads for a building (or building section) and to simulate the operation of the air distribution system in meeting these loads.

b. Total Coincident Requirement. A program to sum the hour-by-hour loads from multiple Energy Requirements Estimate runs for various buildings or sections to find total system loads with actual diversity.

c. Equipment Energy Consumption. A program to simulate the operation of the various pieces of equipment as they respond to loads imposed by the building's air-side systems to find monthly and annual energy consumption for the various systems being evaluated.

d. Monthly Utility Costs. A program to calculate the monthly and annual energy costs for each system using the local utility rate schedules.

e. Economic Comparison of Systems. This program combines typical-year energy costs and other annual operating costs with initial investment and the associated owning cost factors to find the total owning and operating costs of each system year-by-year for any period up to thirty years.

4E.4.1 Energy Requirements Estimate Program (ERE). The ERE program calculates the hourly energy consumption for heating, cooling, process and basic electric loads of a building based on hourly climatic data and building operating schedule. Loads which can be included in the computations are solar; internal, including people, lights, equipment and miscellaneous; return air plenum solar and transmission loads; supply and return loads; outside air; and process loads.

The emphasis and accuracy of this program are primarily devoted to simulating air-side system performance and handling various occupancy and operational schedules, rather than concentrating on the lagging characteristics of transmission loads or the

shifting shade patterns associated with solar loads. The intent of the program is to predict as accurately as possible the overall building energy usage with a minimum of input detail.

Input climatic data includes hourly data of dry bulb temperature, dew point temperature, cloud cover and solar radiation covering a typical year. Such data applicable to a local weather station may be obtained from the National Climatic Center. Subsidiary programs are available to prepare raw weather data for input to the ERE program.

The next step in organizing the input data for ERE is to determine the daily operational schedules of the building and hourly percentages of maximum loads for internal, process, and basic electric. These percentages reflect the movement of people in and out of the building and the resulting changes in load patterns. The maximum loads and percentage profiles are organized into days of the week, and then months, so that an entire year's operation of the building can be simulated. It is important to recognize that input data should reflect actual anticipated load levels instead of design point values used to size equipment.

The next major step in assembling input data is selecting an air-side system and specifying its control features. Typical systems that can be simulated are:

- Single duct;
- Terminal reheat;
- Induction or fan-coil;
- Dual-duct; and
- Standard variable volume.

Additional features that can be utilized in the ERE program are outside air economizer cycle, cold deck reset schedules according to ambient temperature or time clock, heat recovery devices operating between return and outside airstreams, supplemental perimeter heating systems that are independent of central system, holiday scheduling for accurate representation of operating schedules, distinction between on and off peak time periods for electrical service, capability of interrupt gas service and switch to auxiliary fuel, calculation of heat

storage effects caused by shutoff and setback, and the ability to print selected days during the year to observe the hourly behavior of the system.

The output of the ERE program begins with a display of the input data which can also be obtained by using a data checking feature. This is beneficial to the user since it affords an opportunity to check all the values that will be used in the computer and correct any errors.

The output printout includes monthly and annual peaks and consumptions for heating, cooling, process and basic electric loads. The hours of heating and cooling system operation are shown for each month and annually.

4E.4.2 Total Coincident Requirement Program (TCR). The input to TCR program consists of multiple ERE hourly load output tapes plus the data called for on the input forms. A multiplier can be used with each building or section if ERE runs have been made on a unit basis, such as in an apartment complex. The output of the TCR program shows the diversified peaks and time of occurrence, as well as the sum of the individual building peaks. The monthly and annual consumptions are shown for the combined plant loads, and unitized values are printed for peaks and consumptions.

4E.4.3 Equipment Energy Consumption Program (EEC/B). The input to EEC/B program consists of an hourly load tape from ERE or TCR plus the data entered on the input forms. The rated capacities and part load performance are required for each piece of equipment. These data are then broken down into the various systems and the appropriate accessory equipment loads. Typical systems that can be simulated are total energy with heat recovery, gas heating and cooling, gas heating and electric cooling, all electric, and purchased chilled water and steam or hot water. Energy sources may be electricity, natural gas or any other fuel specified.

Features of this program include: different methods of scheduling machines on the line; various sequencing schedules for accessories; separation of on-peak and off-peak electrical usage for special rates; flexibility in handling recoverable heat and heating requirements in each system; multiple ERE or TCR hourly load tapes representing different sections in a building or different buildings in a complex, permitting separate systems in a single complex to be grouped on a single meter.

The output information includes monthly and annual peaks and consumptions for energy input to the equipment in each system. Unitized values are also shown for comparison and checking.

4E.4.4 Monthly Utility Costs Program (MUC). The MUC program uses utility demand and consumption values from a tape generated in the EEC program, plus input cards containing the specific utility rate steps. Alternatively, the demands and consumptions can be entered on cards and the program run independently from any previous program. The MUC program is capable of calculating demand and consumption charges for gas service, electric service, chilled water, steam or hot water, and any special auxiliary fuel. The output shows monthly and annual costs for each energy form in each system as well as average costs per unit of energy and per square foot. The total yearly energy costs (all forms) are also shown for each system.

4E.4.5 Economic Comparison of Systems Program (ECS/B). The ECS/B program uses the energy costs determined in MUC plus other annual operating costs, such as maintenance and operating labor, and combines these costs with initial investment and associated owning cost factors, such as taxes, insurance and depreciation, to find the annual cashflow each year for the life of the system. Annual utility costs and other operating costs can be independently escalated each year by a percentage supplied by the user. The initial investment may be divided into two segments with different depreciation periods, and a provision exists for four additional reinvestments (for equipment replacement or staged projects) which can be on a recurring basis. In addition to straight cashflow and a discounted cashflow of each system on an independent basis, a comparison can be made of each system to the lowest first cost system to show the net savings or reduced operating costs compared to higher owning costs.

4E.5 Available Computer Programs. ERDA is currently in the final phases of development of a building energy study program referred to as CAL-ERDA. Other available programs are listed on page 5-100.

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CHAPTER 5 ENERGY CONSERVATION OPPORTUNITIES (ECOs)

SECTION A - GENERAL

The purpose of this Chapter is to classify and describe building ECOs that apply, generally, to all types of buildings and some, more specifically, to laboratory-office buildings. It is expected that the evaluation of these ECOs for any specific building will be coordinated with the methodologies of Chapters 3 and 4.

These ECOs apply mostly to end-use buildings, rather than to central conversion buildings such as heating and power plants. The complex characteristics of the latter group require special purpose treatment. Although primary conversion systems, (e.g. steam generation plants) are considered in this HANDBOOK, they are not covered in depth.

Building ECOs were grouped in 12 major categories listed at the beginning of this Chapter. Generally the description and application principles are covered in some detail for several ECOs in each category while many others are listed with references and a brief description. The ECOs discussed in detail are those which are either more specifically applicable to laboratory-office buildings or those which are in most cases both significant in their impact on energy consumption and somewhat unusual in their application. Other ECOs considered to be practical and feasible are presented as a listing whenever they have been adequately described in readily available technical literature, reports or studies. References given are listed in Appendix 5.

This HANDBOOK and its ECOs are intended for use by engineering oriented, management operating personnel who are familiar with the fundamentals of building energy systems. It is assumed that specific ECO proposals and their justification will be initiated at that level, with the help of this HANDBOOK.

The sections of this chapter are referenced to corresponding sections in the ECO Related Questions presented in Appendix 1. In addition, a number of general energy management considerations which do not relate to any one energy classification are also presented in this chapter.

Various ECOs presented in this chapter may be applicable to different buildings, depending upon building characteristics and extent of previous energy conservation programs. The asterisk in front of the ECO number in the list of ECOs presented at the beginning of this chapter indicates those ECOs which are considered particularly promising for laboratory-office type buildings at ERDA facilities.

ECO A-1 ECO ORIENTED BACKGROUND DATA (EQ-A)

ECO A-1.1 Energy Related Record Keeping (EQ-A1)

All records of energy consumption should be for the same operating periods. If public utilities are involved with accessible meters, then the consumptions should be logged for all energy purchases simultaneously. These simultaneous readings, rather than the invoice figures and time periods, should be used for energy analysis.

If present public utility policy forbids plant personnel's access to meters, arrangements should be made to gain access for the purpose described.

ECO A-1.2 History of Facility's Energy Conservation Activity (EQ-A2)

A summary description of significant energy conservation oriented changes in systems, equipment, operation and maintenance should be made available. The following data should be included:

- Identification of system involved
- Description of prior operation
- Description of ECO; its purpose and operation
- Cost of implementation
- Expected results
- Actual results

SECTION B -BUILDING SKIN (EQ-B)

In general, the major envelope considerations for existing buildings which affect energy conservation are closely related to HVAC loads, involving solar gains, thermal transmission and infiltration. The factors of insulation, double glazing, storm doors, leakage prevention and solar utilization or reduction have been widely written about and studied from the standpoint of energy, economics and feasibility. Only the areas outlined below, which are somewhat different from the common approach are reviewed.

ECO SK-1 CONSTRUCTION (EQ-B1)

ECO SK-1.1 Sealing of Exposed Surfaces

Many old industrial buildings which were built for natural lighting and ventilation have bays up to 100 feet high with tremendous glass and high U-factor skins which can be a substantial energy waste. A very good case can be made for replacing both fixed and operable glass windows and providing artificial lighting and mechanical ventilation. The ancillary benefits brought about by the lower U-factors, greater ventilation efficiency through judicious location of mechanical equipment and inlet openings, and infiltration control makes consideration of this ECO worthwhile. New, well-constructed buildings with low glass ratios, adequate artificial light and mechanical ventilation have already taken advantage of these principles. There has been much publicity in recent years on the virtues of retrofitting existing or designing new buildings with enough operable window area to provide natural lighting and ventilation in order to save energy. Such recommendations should not be accepted without a careful study of the penalties associated with them. The following factors must be kept in mind:

a. Operable openings cannot be provided without related year-round infiltration or exfiltration energy leaks.

b. It requires highly expensive glazing and hardware to provide glass for natural light without a substantial increase in year round transmission losses and solar gains compared to well-insulated solid walls.

c. Any glass area added only for natural light and ventilation provides such benefit only during the usual 8 to 10 hour daylight occupancy cycle of most buildings. However transmission, solar and air leakage penalties are acting 24 hours/day. The energy losses from this 24 hour penalty will invariably be greater than the potential savings from lighting, fans and refrigeration.

d. The benefits of natural lighting and ventilation are usually available only in perimeter exposed areas (not interior areas) and only during cool, mild weather. The total number of such beneficial hours/year is limited, compared with the year-round penalties.

ECO SK-1.2 BUILDING INSULATION

1. General

This section deals with the energy saving aspects of insulating buildings walls and roofs when the sole benefits derive from changes in the overall coefficient of heat transmission (U); without side effects from sealing against infiltration or exfiltration;when there is no air space between the insulation and construction material or when this space is narrow enough to permit U-factor calculations of composite assemblies without appreciable deviation from actual test results.

2. Manipulation of General Formulae

2.1 The formulae developed in this section are general in nature, applying to any situation within the limits stated above. The infinite variety of permutations and combinations of composite walls and roof-ceiling structure prohibits a practical, short-cut, specific-type approach to the solution of insulation economics.

2.2 This general approach presupposes that the application engineer using such procedures is versed in the techniques (Ref 3) relating to heat transmission, heating and cooling loads.

2.3 For preliminary determination of the benefits in energy and financial savings in this area, it is felt that satisfactory results may be obtained with the use of simplified U-Factor calculations based on steady-state assumptions (rather than hour-by-hour computerized calculations of thermal response) and simpler sol-air and equivalent temperature differential calculations (rather than hour-by-hour computerized transfer function methods). For practical purposes, with differential benefits being sought, rather than absolute values of energy consumption, it is considered sufficiently accurate to combine heating and cooling design load components with Equivalent Full Load Heating and Cooling Hour concepts as employed in this HANDBOOK. (Refer to Appendix 3 for EFL hour calculation.)

3. Energy Savings From Insulation of Buildings

The general formula which may be used to determine annual energy savings from insulation of walls and roofs, as qualified above, is as follows:

$$Q_s = \frac{A\ (\Delta U_h)\ \ (\Delta t_h)\ EFL_h}{1{,}000{,}000\ Eff_h} + \frac{A\ (\Delta U_c)\ \ (\Delta t_c)\ EFL_c}{1{,}000{,}000\ Eff_c}$$

where:

Q_s = Source Energy (millions of Btu) per year saved.
A = Area insulated, sq. ft.
ΔU = Differential in composite U-factor by addition of insulation, Btu/SF/^{o}F (U_h for heating and U_c for cooling)
Δt_h = Winter design temperature difference across insulated wall or roof, F deg. (inside minus outside temperature)
Δt_c = Summer design total equivalent temperature differential across insulated wall, F deg. (outside sol-air temperature minus inside temperature)
EFL_h = Equivalent Full Load Heating Hours per year
EFL_c = Equivalent Full Load Cooling Hours per year
Eff_h = Overall efficiency of conversion of raw source fuel to utilized output energy, heating
Eff_c = Overall efficiency of conversion of raw source fuel to utilized output energy, cooling

ECO SK-2 ENTRANCE PROTECTION (EQ-B2)

1. General

Loading entrances which have a relatively high usage should be considered for protection against infiltration by the use of dock sealers, vestibules, or air curtains.

2. Entries With Short-Perimeter Platforms

2.1 Dock Sealers

When loading areas have narrow loading platforms, commercial dock sealers are sometimes used. These are capable of adaptation to a variety of enclosed truck cross sectional areas. However, they are not readily adaptable to a wide range of sizes, truck door arrangements, angle of back-ups, and some doorways.

2.2 Vestibule Seals

Loading areas with short loading platforms can employ inside or outside vestibule housing, when space permits.

2.3 Advantages and Disadvantages

Presently available commercial dock sealers and vestibules are the most desirable for positive sealing. However, commercial dock sealers are not as durable, positive or rugged as vestibules. Also, they are not adaptable for use at doorway openings that extend down to the same level as the bottom of the truck wheels.

3. Entries With Extended Loading Platforms

Buildings with long loading docks around the building perimeter have almost no choice but to employ air curtains, as an alternative to wide-open, unprotected door openings, assuming that the loading platform requires free traffic movement on either side, for local material handling along the perimeter platform skirt. Without the need for such free movement a section of platform can be vestibuled, for more effective control than is possible with the air curtain. In the latter case, back-up dock sealing techniques can be used at the outside vestibule wall.

4. Entries Too Small For Truck Passage

Buildings with openings too small for truck entry, or those which receive from flat-bed trailers also may employ outside vestibules which house the entire truck and/or trailer. Other buildings which receive closed-body trucks may employ commercial dock sealers with foam rubber

or similar buffers, or curtain enclosures. In this case the truck only backs up to the building wall.

5. Energy Analysis (Heating Season) For Unprotected, Open Doorways

5.1 Variables

The following major variables must be considered for any rational analysis leading to a resolution of the difference in energy requirements of protected and unprotected loading areas:

a) Geographical design winter condition.
b) Area of opening and total hours of usage.
c) Orientation of exposure, angle and force of wind.
d) Number of simultaneous openings in the same or different exposures.
e) Stack effect or infiltration within building as a combined effect of height, number of stories, total crackage, tightness of building.
f) Type of loading such as: unprotected, air curtain, vestibule, dock sealer.

5.2 Lack of Reliable Handbook Data

Accurate evaluation of all these factors is not possible under the present state of the art. Little or no research has been done to permit reliable calculations. Lacking such authoritative data, a basic formula has been developed which can be applied for various combinations in different buildings. There may be disagreement with these figures and factors, but it is felt that the concept is rational. To condense the approach several assumptions are made: two openings on opposite exposures; no penalty for stack effect; 7 mph wind; and the following factors for various loading methods:

F_u = Unprotected = 1.0
F_c = Air Curtain (heated or unheated) = 0.6 (see Par. 6 of this ECO)
F_v = Vestibule = 0 (with allowance for drive-in time as a percentage of total hrs. loading)
F_s = Dock Sealers = 0 (with allowance for set-up time as a percentage of total hrs loading)

Note: Factors for orientation, wind velocity, number of openings, stack effect, type of air curtain as to design, CFM, air velocity and height of throw have all been taken as 1.0, noting that they might vary up or down.

5.3 Open Doorway Heating Load

a) The basic formula for annual energy consumption in 10^9 Btu/yr for an open doorway is:

$$\frac{A \times \text{Unit loss}_o \times F_L \times \text{E.F.L. Occ. Hrs}_{65}}{1{,}000{,}000} \text{ where:}$$

A = Area of door, SF

Unit Loss_o = Design Load with open door at design outdoor winter condition, Btu/SF Doorway (see Par. 5.3b)

E.F.L. Occ. Hrs_{65} = Equivalent Full Load Occupied Heating Hrs/yr derived from the hourly occurrences below 65° F outdoors occurring during the occupied period

F_L = Load Factor on door usage, as a decimal, for the ratio of the hours of Loading/hours of Occupancy.

b) The Unit Loss for an open door is a function of the velocity of air through the doorway at a given wind pressure and direction, expressed by the formula (adapted from Ref. 4).

Unit Loss = $(E \times V) \times 1.08 \times (\Delta T)$, Btu/SF door, where

E = Effectiveness of openings (0.50 to 0.60 for perpendicular winds and 0.25 to 0.35 for diagonal winds)

V = Wind Velocity, fpm = 88 x wind velocity, mph

ΔT = Differential between outdoor and indoor temperature

Unfortunately there is no known available data which expresses the unprotected door's unit loss as a function of orientation, number of openings, stack effect and building tightness. As an example for an area with an average 7 mph wind, 0.3 effectiveness, and a 65°F ΔT:

Unit Loss $= (0.38 \times 7 \times 88) \times 1.08 \times 65$
$= 10{,}977$ Btuh/SF of doorway (unprotected)

noting that this number may be substantially larger with a leaky building, many openings, high stack effect, etc.

6. Heating Load With Air Curtains

6.1 The load reduction with a specific type of air curtain was tested and results for the design indicated (Reference 5). The test results, for a non-recirculatory type of curtain mounted at the doorway of a sealed test chamber indicates a protection efficiency of 80-85%, while the previously mentioned ASHRAE Handbook (Ref.3) cites 60 to 80% (i.e. 60-80% reduction of load).

6.2 In view of the uncertainties involved, such as stack effect, number of other wall openings, etc., it is not felt that the use of a protection efficiency greater than 60% is warranted, unless it is cautiously justified.

6.3 Air curtains may be largely ineffective in buildings with many cross-ventilated openings or a generally leaking envelope stemming from such characteristics as poor structure, high internal suction from multiple stories, or excess of exhaust over supply ventilation.

ECO SK-3 HIGH BAY AREAS (EQ-B3)

Frequently older high-bay industrial buildings are converted to functions which no longer require such heights with their attendant skin losses. Hung ceilings should be considered for such applications, especially if large skylights and windows were employed and air cooling is required for the converted use.

Heat gains and losses occurring through large ceiling air spaces whose self-generated convective air current characteristics prevent the use of normal transmission procedures may be treated by other methods. Calculations may be based upon finding the ceiling cavity "balance temperature" which permits the same heat transmission between the occupied spaces and the cavity (through the hung ceiling) as exists between the cavity and the outside weather (through the roof).

Heat gains and losses through hung ceilings which carry return air (e.g. return air plenum ceilings) are treated with the technique described in Reference 6.

ECO SK-4 ROOF COOLING

Flat and pitched roofs above cooled spaces can be cooled with sprays to virtually eliminate solar gains. Waste water can often be employed. The savings in refrigeration energy can sometimes justify the cost of the spray piping installation. (Ref. 7).

SECTION C - BUILDING COMFORT, USE AND OCCUPANCY (EQ-C)

Original criteria for design and operation should be re-examined and re-evaluated based upon actual building use, occupancy, currently applicable comfort conditions and operating procedures. The effect of such revisions upon comfort, process control and/or inconvenience should be balanced against the benefits. Many of these modifications involve no investment cost.

ECO COM-1 REVISED ROOM TEMPERATURES (EQ-C1 & C2)

Room temperature can be raised during cooling periods and dropped during heating periods. Energy savings can be evaluated by analysis of the EI nodes which are affected, in Form 3-3, Page 1 of 11 for cooling and Page 5 of 11 for heating.

The nodes which are affected as a direct function of outside/inside temperature difference (ΔT) are EI_t (transmission) and EI_s (solar). (The effect on EI_v is one that combines with any simultaneous change in room humidity, covered in ECO COM-2)

a. The new ΔT for EI_t is = (design outdoor dbt) - (room dbt) for both cooling and heating

b. The new ΔT for EI_s is = (equivalent sol-air dbt) - (room dbt) This difference is approximated as

(Solar Load/Transmission Load) (Original ΔT)

Raising cooling season room temperature settings does not necessarily save energy from the EI_t and EI_s standpoint, when reheat and dual duct types of systems employ a non-renewable source energy for heating the space while it is simultaneously absorbing mechanical cooling. The savings in refrigeration energy from reduced transmission and solar gains may be wiped out by the additional source energy required to heat the room to the higher level, if the cooling coil leaving air conditions are left the same as they were for the lower room temperature.

However, if a higher room temperature is accompanied by a number of techniques, including the following, then savings are substantial:

a. Raising the coil leaving air temperature to maintain the same supply air-to-room ΔT (see condition 2 vs. condition 1 in Fig. APP 3B-1).

b. Using a cooling cycle such as VAV, which permits the system energy provided to track the load without the engagement of reheat.

ECO COM-2 REVISED ROOM HUMIDITY (EQ-C1 & C2)

Room humidity (RH_r) may be raised during cooling periods and dropped during heating periods when year-round humidity control is employed. Savings may be analyzed by examination of the ventilation and reheat nodes, as above.

The EI_v is a direct function of the outside/inside enthalpy difference, as long as the cooling coil and humidification controls are capable of responding to the revised RH conditions. For example the summer room RH may not rise, as desired, if the cooling coil discharge dew point is too low to permit this to happen.

An additional benefit for higher cooling season RH_r is the reduction of reheat energy required.

ECO COM-3 REVISED VENTILATION CRITERIA (EQ-C1 & C2)

When exhaust flow requirements and governing ventilation codes are below present make-up ventilation needs, the latter may be reduced to the minimum acceptable level. Design quantities are often in substantial excess of acceptable values.

A variable minimum ventilation quantity, as a function of occupancy should be considered when occupancy loading varies substantially from day to day or throughout the day.

Other aspects of ventilation control and reduction are covered under ECO HA and ECO HVE.

ECO COM-4 CONSOLIDATE FUNCTIONS (EQ-C4)

Consideration should be given to the grouping of functional areas which have similar conditioning criteria, for handling by common HVAC systems. Energy savings are possible when widely diverse criteria are handled by separate units, with control of energy output levels for each specific need, rather than by satisfying the worst need in a group of diverse loads with a common unit.

ECO COM-5 LET THE OUTPUT TRACK THE USAGE PROFILES

Usage modes of all diverse areas should be systematically identified with particular attention to special process or comfort criteria, extended after-hour use of energy systems and the extent of criteria reduction during such extended use.

The usage modes should then be evaluated for modification (e.g. reduced operating hours, less energy-intensive criteria). Given the modification, the energy systems involved should be checked to determine whether they can satisfactorily track the load at this reduced energy level, and, if not, what system modification is required to do so. See ECO HR-2.1 and HCR-5.2 for illustrations.

SECTION D - ELECTRICAL SYSTEMS (EQ-D)

In "non-shop" areas such as administration buildings, office areas, warehouse and commissary facilities, more than 50% of the total building utility costs is for electricity. A minimum of 3 units of fossil fuel energy (coal, gas, oil) are required to produce and deliver one (1) unit of electric energy. Thus, by conserving electrical energy we save the equivalent of 300% in fossil fuel raw "in-ground" source energy.

This section presents possible ECOs within electrical systems such as service and distribution, power generation, load management, lighting and maintenance. One or more of the ECOs presented can be applied to each of the facilities under consideration.

The effects upon electrical energy-saving of ECOs in other systems and procedures are discussed as complementary to the ECO descriptions for those other systems elsewhere in this HANDBOOK. Examples are ECOs within mechanical systems, building equipment, operation schedules for occupancy and usage and maintenance schedules.

5D.1 - SERVICE AND DISTRIBUTION

This subsection presents possible ECOs within transformer stations, through voltage regulation and within building electrical distribution systems.

ECO ES-1 TRANSFORMERS

ECO ES-1.1 UTILIZATION OF EFFICIENT TRANSFORMERS

The efficiency of most dry-type transformers ranges from 93% to 98%. The losses occur from the core (magnetizing), and coils (resistive and winding). Select the most efficient dry-type transformers when replacement is required.

Dry-type transformers are available in many termperature-rise classifications. The lower the temperature-rise rating, the lower the coil losses due to the larger conductors used in the winding. 80°C and 115°C are usual temperature rise ratings. Selection of the 80°C rise transformer is recommended because of both greater efficiency and longer life expectancy. These advantages may offset the higher cost of these transformers (about 70% higher than the high temperature-rise dry types).

If larger oil-filled transformers are required for new additions, the highest efficiency transformers should be selected. Note that oil-filled transformer efficiencies vary in large installations.

ECO ES-1.2 REDUCTION OF TRANSFORMER LOSSES

Reduction of transformer losses, discussed in the SITE ENERGY HANDBOOK, Volume 1, Paragraph 5D.4.1, also applies to energy savings in building distribution systems.

Many buildings include redundant electrical system components, principally to assure reliability of service. This has resulted in the installation of transformer capacity in excess of system load needs. Main service transformer capacity should be capable of supplying present maximum demand plus immediately foreseeable loads. Total distribution transformer capacity need not exceed 2 to 2.5 times peak demand.

Deenergizing the excess capacity and redistributing loads can result in reduction of transformer load losses and more efficient transformer operation. No loss in reliability will be experienced where switching of primary and secondary feeders is under manual control. Where automatic transfer is in use, the sacrifice in transfer time lost by changing to manual operation must be evaluated.

Rearrangement of feeders to permit deenergizing some transformers at times of reduced facility usage (such as unoccupied hours) will improve the feasibility of this ECO.

It is recommended that a maintenance heating circuit be added to outdoor transformers, whether dry-type or liquid cooled, to prevent the deleterious effects of moisture on insulation while deenergized. The cost of this modification must be included in the pay-back analysis of this ECO.

ECO ES - 2 VOLTAGE REGULATION IMPROVEMENT

Under most conditions, voltage regulation of plus or minus 5% is satisfactory. When low voltage or poor regulation is encountered, consideration should be given to improving either or both.

The evaluation to be made is the installed cost of voltage improvement equipment compared to the energy saving of reduced losses and improved efficiency of operation ,lighting, motors and equipment.

Consideration to accept reduced voltages may prevail, on the other hand for incandescent lighting as an energy saving means. This may apply where the reduced efficiency does not result in leaving additional lamps energized in order to compensate for reduced lighting level.

Off-normal voltage affects energy usage and process efficiency as well as raising costs:

- A 7% undervoltage reduces furnace operation by 14%.
- A 3% overvoltage means 30% less life for incandescent lamps.
- Low voltage limits the performance of machine tools and other apparatus.

Voltage regulators and stabilizers are available in a large assortment of sizes, types and operation methods. They can be applied in sizes to suit a sub-system for voltage-drop compensation or particular items of equipment and apparatus.

Types of voltage regulators and stablizers include variable ratio autotransformers, saturable reactors, static type units using triacs. An automatic voltage-drop compensation system in a single unit is available, comprising a series transformer fed from a motor-operated, variable ratio shunt transformer.

Decisions on the application of voltage regulation equipment should be made under the direction of a qualified electrical engineer.

ECO ES-3 Reduction of Distribution Feeder Losses

Reduction of line losses by load sharing between feeders as described in SITE ENERGY HANDBOOK, Volume 1, Paragraph 5D.4.2 applies as well for the building distribution system. In addition, line losses may be reduced by balancing of phases.

5D.2 - POWER GENERATION

Energy conservation opportunities may be possible through the use of on-premises generation. Electrical energy cannot be generated as economically as it can be purchased from an electric utility company, unless turbine extraction or exhaust steam is used for heating or process requirements or waste heat generated is reclaimed and its value deducted from the cost of power generation. In this case, the cost of on-premises electrical generation is often competitive with purchased electricity.

ECOs in this category are based on the total energy (T/E) and selective energy (S/E) concepts. These concepts and the ECOs involved are similar to those presented in the SITE ENERGY HANDBOOK for on-site generation.

Following is a listing of building ECOs involving on premises power generation and the corresponding site ECOs in the SITE ENERGY HANDBOOK, to which the reader may refer for ECO descriptions and related calculations.

ECO EG-1 Total Energy (T/E) - Refer to ECO E-7 in SEH

ECO EG-2 Selective Energy (S/E)

ECO EG-2.1 S/E With Fixed Segregated Load No Utility Standby - Refer to ECO E-9 in SEH

ECO EG-2.2 S/E with Segregated Load and Utility Standby - Refer to ECO E-10 in SEH

ECO EG-2.3 S/E with Variable On-Premises Portion-Paralleled with Utility - Refer to ECO E-11 in SEH.

ECO EG-2.4 S/E with Variable On-Premises Portion-Without Paralleling - Refer to ECO E-12 in SEH.

ECO EG-2.5 S/E for Variable On-Premises Shaft Power - Utility Alternate - Refer to ECO E-13 in SEH.

5D.3 - LOAD MANAGEMENT

Load management principles can be applied to reduce electrical consumption through scheduling of equipment usage and power factor improvement. Scheduling may also be used to limit electrical demand and reduce demand penalty charges. Load management principles applied to lighting are presented in Section 5D.4.

The following factors should be considered when assessing the feasibility of ECOs through load management:

a. Load Factor

The use of load factor analysis to maximize distribution system usage is discussed in the SITE ENERGY HANDBOOK, Volume 1, paragraph 5D.6.

The application of this method to building electrical distribution systems is useful for improving system efficiency and lowering demands.

b. Instrumentation

The application of multiple circuit demand indication is useful for load control and energy budgeting, where feeders or portions of the electrical distribution systems serve specific functions or building areas.

Instantaneous indications at one central control location within the building facilitate decision making for on-off operation. Recording these data will permit evaluation for energy budgeting.

Expansion of an existent building automation system can readily accomodate additional energy monitoring and control functions.

ECO ELM-1 REDUCTION OF ENERGY CONSUMPTION

Typical means of reducing consumption are listed below.

a. De-energize all current consuming devices and equipment (transformers, motors, etc.) during non-use periods, if feasible.

b. Revise schedule of low load factor operations to provide meaningful shutdown periods for portions of the building. Where a laboratory or shop is only 80% active, it could be operated 4 days a week to permit a one day shutdown of the space. A reduction in both environmental and lighting energy and demand would be achieved.

c. Schedule custodial functions to normal working hours or to daylight periods for energy savings.

d. Re-schedule the normal work-day to make use of additional periods of natural light.

ECO ELM-2 POWER FACTOR IMPROVEMENT

The advantages of power factor improvement are described in the SITE ENERGY HANDBOOK, Volume 1, paragraph 5D.5. Power factor improvement saves energy by reducing the Utility's generating requirement and transmission losses. It also reduces distribution losses on feeders and transformers within the facility and current flow for the required work. The resulting reduction of voltage loss permits more efficient operation of motors and lighting.

Power factor improvement can be achieved by the use of synchronous motors, synchronous condensers or by static capacitors. Using synchronous condensers should be considered in buildings with heavy industrial loads. Synchronous motors may be used in lieu of induction motors, in the larger horsepower range. Evaluation must include disadvantages as follows:

. higher installed cost compared to use of induction motors with corrective capacitors;

. additional cost for exciter, exciter generator and controls;

. higher maintenance costs.

Capacitors are more economical, highly flexible,easier to install, with low maintenance and life expectancy of 10 to 20 years.

There are 3 methods of application of power factor improvement. One is group installation at the electric service entrance. A second is group installation at switchboards, distribution panels or motor control centers. The third is at the individual units of low power factor equipment. This latter method is most preferred for reducing losses and improving voltage levels for the facility as well as for the utility.

Ratings of capacitors for application to individual motors is presented in Table ELM 2-1 in Appendix 4. These ratings are in accordance with IEEE recommendations and are expected to improve power factor to about 95%. Installing the capacitor at the motor permits disconnecting the motor and capacitor as one unit without separate switching.

There may be economic advantage, however, to installing grouped capacitors at motor control centers or other distribution points. This may particularly apply in retrofit cases where motors are not readily accessible. Automatic capacitor switching equipment should be considered in these cases, to avoid excessive leading reactive currents when some motors are not operating.

Table ELM 2-1 also shows line current reduction in percent. Line losses will vary with circuit parameters, size of conductor, length of run, type of raceway.

Savings will be evident considering that resistive losses vary as the square of the current; eddy current losses as the cube; and iron conduit losses as the fourth power.

In evaluating the use of individual capacitors or distribution group installations the following considerations apply:

- individual capacitors cost more per KVAR than larger capacitors;

- wiring costs for individual capacitors may be greater than for grouped.

A common practice is to use individual capacitors to correct motors rated 15 horsepower or higher and grouped capacitors for groups of smaller motors. Conditions at a particular facility may favor grouped installation for other combination of motors.

In application, total correction capacitor KVAR is determined. Corrective capacitors are applied to individual motors and grouped distribution points as described above. The ratings of these capacitors are then deducted from the total required. A corrective capacitor equivalent to this difference is installed as a service entrance group.

Table ELM 2-2 in Appendix 4 may be used to determine building power factor improvements when kilowatt load and average building power factor are known.

An example of use of Table ELM 2-2 follows. If:

a. kilowatt load is 400 KW;

b. average power factor is 76%; and

c. correction required to 85%; then

d. read horizontally at line .76, vertically at line .85; with the applicable multiplier of .235,

e. KVAR capacity required is: .235 x 400kw = 94 KVAR

Economic evaluation of power factor imporvement at the electric service can be readily performed, whenever the utility rate schedule includes a charge for low power factor (usually below 85%, where present). The utility charges at the low power factor can be found; charges at the corrected power factor can be computed.

Typical installed cost of capacitors for grouped installation is $10 per KVAR for 480 volts and $20 per KVAR for 208 volt or 240 volt use.

Cost evaluation for individual motor or distribution point group cases is more complicated, involving line losses and equipment efficiencies. For ECO evaluation, computations may be made for the most salient cases: larger motors, power factors of 70% and lower, long feeder runs.

ECO ELM - 3 DEMAND LIMITING (EQ-D4)

ECO ELM - 3.1 LOAD SHEDDING

Peak demand may be limited automatically or manually. Selection of the associated method of monitoring and control can be made through a cost payback analysis for each facility. Considerations in this analysis are:

- Presence or addition of control equipment; contactors, circuit breakers, starters, for local or remote shutdown;
- Frequency of shutdowns permissible for large horsepower equipment;
- Availability of building management personnel to perform load control operation;
- Presence or addition of monitoring or instrumentation to permit decision making.

Potentially manageable loads within each building may be selected from the representative group listed below. Options within each building for these loads should be analyzed conjunctively by the building and for process management divisions.

Potentially manageable loads are:

a. Heating, Ventilation and Air Conditioning Systems

Electric reheat coils
Supply and recirculation air fans
Compressors
Electric boilers
Chilled water bypass valves
Damper systems
Intake and exhaust air fans
Electric space heaters

Self-contained air conditioning units

b. Process Equipment

c. Building Support Systems

Hot water circulation pumps
Sump pumps, sewage ejectors
Toilet exhaust fans
Selected elevators in a group
Selected lighting circuits
Hot water heaters
Electric water coolers
Vending machines
Incinerators
Waste compactors

Other types of load suitable for shedding at peak periods in addition to those listed above may be identified.

Selection of manageable loads is made on the ability of systems to "coast" for up to 10 minutes during peak demand periods. The effect of load shedding upon system operation for optimally selected manageable loads will not be noticeable. Where critical groups of loads are present, an additional level of control can be used to cycle each element for portions of the demand period.

Many options are offered for demand limiting, load shedding and demand monitoring equipment. The equipment is low-cost, trouble-free, easy to maintain and control, and quite often easy to install. Installation costs will vary with individual buildings and depend upon lengths of runs for control wiring and the presence of or need for magnetic contactors, motor operated circuit breakers or other power control devices. Total costs will usually determine a payback of from 3 months to 3 years.

<u>ECO ELM-3.2 SCHEDULING</u>

Load management principles can be applied to reduce demand by rescheduling simultaneous intermittent loads.

Examples are as follows:

- Operate water cooling and water heating equipment in off-peak periods where storage facilities are present.

- Use off-peak periods for such building functions as data processing, machine shops, auxiliary laboratory work, etc.

5D.4 - LIGHTING

Selected energy conservation opportunities within lighting are presented below.

ECO EL-1 LIGHTING INTENSITY REDUCTION AND OPTIMIZATION

The ECO available from reducing lighting intensity exists in any building designed to prevailing standards of the past 25 years.

Reduction of energy usage for lighting can be achieved by one or several of the methods listed below. Even where one of the ECOs has been implemented, a new evaluation should be made using up-dated criteria discussed herein.

A summary of ECOs to consider are as follows:

a. Lamp removal where reduced lighting intensity is acceptable.

b. Addition of fluorescent ballast switching where fluorescent lamps are removed.

c. Replacement of present lamps with units of higher efficiency, i.e. fluorescent for incandescent; high intensity discharge for fluorescent or incandescent.

d. Replacement of present luminaires with units of higher efficiency.

e. De-energizing lighting when space is not occupied, when tasks are not being performed or when natural light is suitable.

f. Dimming of lighting to suit level required for task being performed or to take advantage of natural light available.

g. Redesigning lighting in accordance with task/ambient criteria.

While many of these ECOs may have been implemented during prior energy savings programs, in all likelihood, lighting design has not been applied. Where it has been, current task/ambient,non-uniform lighting criteria may not have been considered. In this event, a review of lighting ECOs implemented to date is worthwhile to attempt to increase energy savings and to maintain effective task-oriented lighting.

Installation work may be required to implement some of the ECOs within Lighting Intensity Reduction listed before. The economic evaluation of an ECO in this category may obviate implementation on an economic basis. However, the obvious reduction of lighting is an effective demonstration of committment to energy conservation. Therefore, each area, especially management offices, should implement reduced lighting, even where energy savings achieved are of minor significance. The prototype set by management will influence the attitude of all personnel.

EL-2 TASK/AMBIENT LIGHTING DESIGN

Use of task/ambient lighting design criteria to remodel existing space will offer an ECO in reduced energy use while maintaining lighting levels for task performance.

Design criteria in the "cheap energy" era permitted excessive lighting levels without excessive costs. The approach to lighting design favored modularity, limited control selection, uniform lighting levels for ambient and task purposes. Life cycle costing calculation for these existing installations considering present high energy rates and future higher rates may prove it advantageous to invest in task/ambient lighting systems. This usually proves to be economically feasible even considering the depreciated value of the existing equipment.

In redesigning lighting systems the current practice of using non uniform task/ambient lighting will offer energy saving with little or no effect on performance of building operations. Present criteria of 2.25 to 2.5 watts per square foot for overall building lighting can produce sufficient illumination to meet IES recommended intensities. The program requirements for redesigned space should follow these criteria.

An energy conservation-minded lighting designer can select lamp sources of higher efficiency, improved luminaires and more sensitive concepts to meet these criteria.

Lighting levels required to meet the Federal Energy Administration directive for all government buildings should be used where applicable. The FEA intensities are as follows:

	Footcandles
Offices	50
Conference Waiting and General Rooms	30
Corridors	10

Preparation of a lighting power budget will be a useful guide to determine the implementation of lighting energy reduction in an existing building. Indiscriminate removal of lamps may be an example of an ECO with sometimes undesirable consequences. While removing of lamps reduces energy usage, the lighting environment created may be unsuitable for safety, productivity and adequate use of the building's potentials.

The lighting power budget determination procedure is described in ASHRAE Standard 90-75, ENERGY CONSERVATION IN NEW BUILDING DESIGN, Attachment B. The form for calculation, therein, makes use of data collected in the energy survey and requires choices to be made by the energy analyst.

Illumination level criteria indicated are those in the IES Lighting Handbook, 5th edition figure 9-80 and various ANSI standards covering lighting practice.

Illumination levels should be selected from other criteria which may exist for the facility, such as Federal Energy Administration standards and FPMR 101-20.116-2.

ECO EL-3 SELECTIVE LIGHTING CONTROL

Existing installations often contain too few selective swithing means to control groups of light. To implement some of the ECOs listed above, added local wall switches should be considered. Personnel using space can make choices on which lights should be off based upon:

- occupancy
- task performance
- natural light condition

Other means of lighting control besides local wall switches and large area control or panel circuit breaker control should be considered from the following:

a. Manual time switches to replace local wall switches in intermittently used space such as reference files, storage, mechanical equipment rooms, elevator machine rooms, offices associated with laboratories.

b. Automatic time switches or photoelectric controls for lights in areas with natural light available.

c. Automatic time switches to reduce corridor lighting levels in unoccupied periods.

d. Pull chain switches mounted on existing knockouts of pendant luminaires in work spaces. Often a prior lamp removal program has left many areas without light available when needed and without a means of turning off when no task is being performed.

An example for evaluating substitution of manual time switches for local wall switches follows.

An intermittently occupied space may be actively used for 1000 hours per year. Idle time when lights are left burning needlessly during the work-day, overnight and on weekends may approach 2000 hours per year based on a 25% "forgetfulness" factor. A space with 4 fluorescent luminaries rated at 200 watts each would consume 800 kWH/year for a cost of $24 per year at a 3¢/kWH rate. The installation of a manual time switch in place of the standard wall box snap switch is estimated to cost less than $30 for labor and material. This would mean a pay-back of less than 2 years. Larger spaces with more luminaires involved would produce faster paybacks. Similar evaluations may be made for the other opportunities listed.

ECO EL-4 REPLACEMENT OF LAMPS

Fluorescent lamps are presently offered to operate at reduced wattages, while also producing less light output. This ECO can be applied without added installation costs as a replacement program.
As an example, rapid start fluorescent lamps are available as follows:

4' Rapid Start	:	35w. for 40 w.
1"-8' Slim Line	:	54w. for 50 w.
1 1/2"-8' Slim Line	:	60w. for 75 w.

8' High Output	95w. for 110 w.
8' Power Grove	143w. for 215 w.

Use of these lamps will offer a 10% energy reduction, 20% light reduction, 27% increase in lamp costs for rapid start and a 3 to 12% increased cost for the other types.

Caution must be used in implementing this ECO. Some manufacturers of ballasts, are reported to have withdrawn the guarantee for ballasts when these lamps are used; other manufacturers maintain the ballast guarantee.

When reducing the lighting level in areas illuminated by two-lamp series ballast fluorescent light sources, all lamps controlled by a ballast must normally be removed. If only one lamp were removed, the life the of ballast and remaining lamp would be severely reduced. The resulting lighting level variation between operating sources may, however, be unacceptable.

Phantom fluorescent lamps which provide no light and consume no power are available for the replacement of single lamps in two lamp series ballast. Phantom lamps are available in two designs. One type replaces the lamp with a 2.5 mfd capacitor. Another type replaces the lamp with a solid wire conductor. The phanton lamps are similar in structure to fluorescent lamps.

Substitution of a single lamp by a phantom lamp will reduce electrical energy consumption. However, efficiency of light output decreases and the reduction in lighting level will be proportionally greater than the reduction of energy consumption. Ballast losses remain constant even though one lamp is removed. A decrease in life of the remaining lamp may also be anticipated. Power factor is, in addition, adversely affected.

Improved incandescent lamps that provide the same lumens at 10% reduced wattage are available. Lamp cost is higher. These are krypton-filled lamps offered in sizes of 36, 54, 69, 93 and 143 watts, long life to match standard long life ratings of 40, 60, 75, 100 and 150 watts, respectively.

5D.5 - MAINTENANCE

Proper sizing of equipment, selection of voltage ratings and nominal system voltages are essential for efficient operation and minimization of losses. Maintenance procedures can be established to provide ECOs in routine inspection, adjustment of the electrical system and in equipment repair and replacement.

ECO EM-1 VOLTAGE LEVELS

Most building electrical systems were probably adequate when first designed and installed. Since that time changes in connected load and system deterioration may have affected the working voltage level. Loose connections and poor contacts result in increased circuit resistance and low voltage conditions. Low voltage to motors results in high current demand and increased line losses. Overvoltage, on the other hand, decreases motor efficiency.

A load survey will indicate problem circuits and identify deteriorated conditions. After repairs and upgrading are effected, regular voltage checks should be made.

ECO EM-1.1 TRANSFORMER TAP SETTINGS

Adjustment of transformer tap settings may optimize nominal voltage level at utilization equipment. The voltage level should be set within the tolerance of equipment rating, for the largest energy-using items in the sub-system.

ECO EM-1.2 MOTORS

Where motors are dual-rated, winding connections should be checked so that 220 volt motors are not operating on nominal 208 volt systems.

In replacing or rewinding burned-out motors, new motors should properly match the available supply and load requirements.

ECO EM-2 LIGHTING

ECO EM-2.1 LAMPS

Unless difficult accessibility for lamp replacement is a forebearing consideration, long-life incandescent lamps should be avoided. These are usually 130 volt rated lamps for use on nominal 115 volt systems. By operating at under rated voltage, in this example at 89% of rated, lamp life is increased

to 500% expectancy, with 80% efficiency (lumens per watt). However, light level is 67% of rated. Where a lamp removal ECO has been implemented in this situation, extra lamps may have been left connected for higher wattage input than is required for the reduced light level. Operating at improved efficiency may offer the opportunity to reduce additional lamp wattage.

ECO EM-2.2 LUMINAIRES

Optimum luminaire maintenance procedures will improve energy usage. Group replacement of aged lamps rather than upon burn-out will afford an ECO in permitting fewer lamps to be required in some cases. Cleaning of reflectors, shields and lenses of luminaires will improve energy usage in the same manner.

ECO EM-2.3 BALLASTS

Ballast replacements on burn-out can be selected from modern more efficent types available today. One manufacturer offers an 89 watt, 2 lamp 40 watt fluorescent ballast to replace the previously available 92 to 95 watt units.

Multilevel ballasts with selectable tap settings at 100%, 55% and 37.8% input and output are available to permit flexibility in changing light levels to suit various space function requirements.

SECTION E - HEATING AND COOLING SYSTEMS (EQ-E)

This section includes ECOs associated with space heating, ventilating and cooling for both process and comfort purposes. It covers the individual building conversion plant and distribution systems as well as the terminal devices. Energy systems which are common to the various HVAC energy classifications are covered under other sections (e.g. pumping, coolant, control and waste recovery systems). There will be some overlap because no single classification is so distinct that it can be considered completely apart from at least one or two others.

Because of the infinite number of variations in HVAC and Refrigeration Systems, their variety of combinations and their application or use, the objective of this section will be to catalogue areas of systems and equipment design, operation, and maintenance which have a more pronounced effect on energy consumption.

Any energy system, no matter how well conceived and designed for optimum conservation, can become a wasteful consumer of energy if not properly installed, operated or maintained. Since this Handbook deals with existing facilities, rather than design of new systems, the thrust is on retrofit ECOs, rather than new design.

General observations and most rules and guidelines as to wasteful systems or procedures are not necessarily applicable to all situations. It is not feasible to cover all possibilities therefore the conclusions reached are intended to be for specific parameters cited in each situation, rather than broad, all-inclusive ones.

Discussion will be largely confined to those system and design characteristics which have practical and economically justifiable alterable potential.

5E.1 - FUEL HANDLING AND COMBUSTION SYSTEMS (EQ-E.1)

This section includes the handling and preparation of fuels, as well as their firing and combustion control. Related ECOs may be found in Section 5K.2 "Combustion Air & Flue Gas Systems" and Section 5I "Industrial Process-High Fuel Consumers".

ECO HF-1 COMBUSTION CONTROL SYSTEMS (EQ-E.1c & E.1d)

1. Ideal Combustion Efficiency

   Ideal combustion efficiency is attained when the products of combustion contain no CO, H_2, hydrocarbons, nor O_2 (0% combustibles, 0% oxygen), or with the fuel/air ratio adjusted for a maximum percent CO_2 (Figure HF 1-1). This requires perfect atomization without flame impingement or any other form of flame quenching.

2. Actual Attainable Combustion Efficiency

   When burning oil, it is often necessary to provide excess air to complete combustion. Efficient combustion is not attainable with burners using mechanical positioning controls for the following reasons:

2.1 Variable air density will affect the fan's ability to deliver air (oxygen). An air deficiency of 1% can waste as much heat as 10% excess air.

2.2 Variable fuel analysis.

2.3 Poor maintenance of the combustion system.

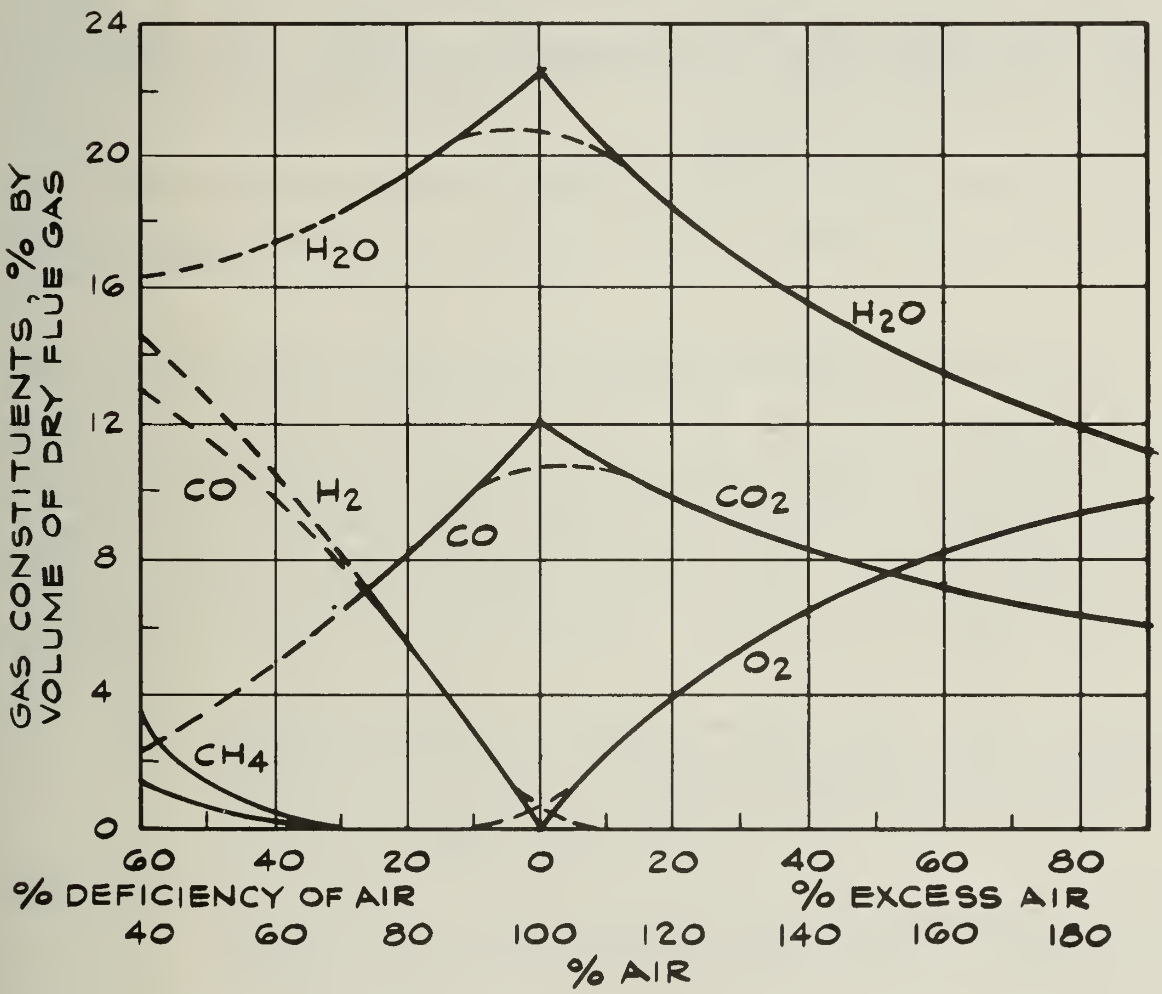
3. Combustion Controls

3.1 Instruments are available which continuously measure CO_2 and stack temperature and give a direct reading of boiler efficiency. These provide boiler operators with the requisite information for manual adjustment.

3.2 In large boiler applications it is recommended that more sophisticated controls be considered.

FIG. HFI-1

FLUE GAS ANALYSIS VS % COMBUSTION AIR



IDEAL COMBUSTION WOULD BE WITH 100% AIR, OR 0% EXCESS AIR. ON EITHER THE RICH OR LEAN SIDE OF THIS CONDITION, EFFICIENCY AND % CO DROP OFF, AND %O OR COMBUSTIBLES INCREASES: DOTTED LINES INDICATE EFFECTS OF POOR MIXING OR FLAME QUENCHING.

4. Combustion Efficiency Calculations

Figures HF 1-2 through HF 1-8 in Appendix 4 contain excerpts from References 8,9, and 10 and show two methods of calculating combustion efficiency for the purpose of evaluating savings from its improvement. Reference 8, with commonly used tables of "Total Heat Loss" in flue gas as a function of only % CO_2, flue gas and room temperature is not as versatile and accurate as Reference 9 which accounts for several other flue gas losses (e.g. water vapor, CO). Reference 10 shows the relationship between the various parameters at varying excess air ratios.

ECO HF-2 REPLACE OR MODIFY STEAM BURNERS WITH AIR ATOMIZATION

The replacement of existing steam atomizing burners in good condition or obsolete burners with air atomization should be evaluated for possible benefits. Existing steam atomization can sometimes be changed to air with minor burner retrofit. Steam added to the products of combustion lowers its dew point and tends to increase corrosion when economizers, air preheaters and other recovery devices are used which reduce stack temperature. The higher the flue gas dew point, the more heat can be recovered safely without acid condensation in high sulfur fuels.

The comparison analysis forms, Figure HF 2-1, presented in Appendix 4 illustrate a calculation procedure which may be used to evaluate this ECO.

ECO HF-3 FUEL OIL PREPARATION AND HANDLING (EQ E.1a & E.1c)

Several ECOs may be considered. Two of them are briefly outlined below.

ECO HF-3.1 AVOID CONTINUOUS PUMPING OF FUEL OIL (EQ E.1a)

Avoid continuous pumping of fuel oil, when the installation of a day tank (sized as permitted by Code) allows a reasonable "On-Off" cycle period for the transfer pump. It should be considered for systems which would not result in a high-viscosity pumping problem due to off-cycle cooling. The burners require pumps that can take suction from the day tank and deliver the pressure required at the burners. There are a number of possible benefits:

a. Pumping energy savings (see ECO P-1) result from the combined effect of pumping "off" time and the reduction of both flow rate and discharge and pressure required by continuous pumping which must employ pressure relief bypass.

b. Reduction of heat loss from main storage tank as a result of reduced volume of hot fuel oil return back to this tank.

ECO HF-3.2 MONITOR AND CONTROL FUEL OIL VISCOSITY (EQ E.1.a5 & E.1.c.1)

The greater the variation of characteristics in fuel oil from delivery to delivery, the more important is its monitoring for the optimum preheat temperature and most effective atomization for each batch. Such adjustment may be manual or automated. Table HF 3-1 (Reference 10) gives the desired operating temperature for various fuel grades and viscosities.

TABLE HF 3-1

TEMPERATURES REQUIRED FOR PUMPING & ATOMIZATION OF TYPICAL FUEL OILS*

	SSU at 100°F	SSF at 122°F	TEMP(F)REQ'D FOR 2000 SSU (EASY PUMPING)	TEMP(F)REQ'D FOR 100 SSU (ATOMIZATION)
Typical No. 4 Oils	50	-	-	+44
	60	-	-23	64
	75	-	-9	82
	100	-	+6	100
Typical No. 5 Oils	150	-	24	121
	200	-	32	134
	300	21	45	151
	400	26	54	162
	500	30	62	171
Typical No. 6 Oils	1000	50	82	195
	2000	100	100	217
	3000	135	111	231
	4000	160	116	238
	5000	190	122	245
	10000	342	138	264

*Reference 10

5E. 2-HEAT GENERATING PLANTS

This subsection classification includes all types of generators which convert depletable source fuel or electricity to heat, for comfort or process. Refer to Sections 5I "Industrial Process and 5K "Waste Energy Reduction and Recovery" for related ECOs.

ECO HH-1 DEVELOP LOGS FOR PERFORMANCE MONITORING (EQ E.2.a)

Take full advantage of existing instrumentation and consider additional instruments and meters (See Section 5J) to permit on-line monitoring of sufficient parameters for calculation and logging of daily as well as full and part-load conversion efficiencies.

Such evaluation logging should consider the following determination for steam plants from consistent physical units or Btu equivalents:

1. Combustion Efficiency = Gross steam generated/fuel input
   a) From stack gas analysis (see ECO HF-1)
   b) From direct input fuel and generated steam measurement (see SITE ENERGY HANDBOOK)
2. Plant Efficiency = Net steam sent out for useful consumption/fuel input
3. % Condensate Return = lb condensate returned/lb steam generated. When possible this should be on an individual boiler basis.

For other heat generating devices (e.g. hot water generators, furnaces, etc) similar monitoring should be made possible - on a continuing regular, periodic basis for larger equipment and on a longer-period, spot-check basis for smaller ones.

ECO HH-2 IMPROVE HEAT BALANCE (EQ E.2.c)

Steam generating plants which employ substantial quantities of steam for power auxiliaries and plant heating services require more sophisticated logging and analysis for on-going optimization and overall favorable heat balance. Extensive treatment of this subject is beyond the scope of this HANDBOOK.

ECO HH-3 AVOID STAND-BY FIRING OF RESERVE HEAT GENERATOR

Any time multiple generators are kept on line at low loadings, as a normal operating procedure, a full re-evaluation of the need for this procedure is recommended. Criteria which must be examined include the following:

1. Are there any emergency steam turbogenerators?

    a. What is their maximum combined steam demand and how long is the time period from power failure to full demand?
    b. What percentage does this represent of each boiler's capacity?
    c. What is the time period required for each boiler to come up to the turbogenerator minimum steam pressure at a delivery rate equal to their combined demand?
    d. Are there any other major steam demands which might simultaneously cut in during a take-over of emergency turbogenerators? How essential are such loads, and can they be automatically deferred in the event of a power failure?

2. Are there any non-essential steam loads which can be automatically shed for the period of time required by a stand-by boiler to assume load?

ECO HH-4 REDUCE BLOW-DOWN LOSSES

Install orifice in series with blow-down valves to avoid wire-drawing of valve, subsequent wear and excessive continuous blow-down or leakage when closed. Automate blow-down from TDS sensor to avoid unnecessary losses from excess blow down, or damage from too little. Provide a means for visual inspection of leakage in intermittent blow-down piping system. Consider installation of heat recovery exchangers in blow-down and flash tank circuitry.

ECO HH-5 REDUCE STACK LOSSES

Install automatic draft control dampers in breeching to shut 30 seconds after burners and to open 30 seconds before next firing cycle, to slow down boiler cooling between firing cycles. Consider the installation of baffles or turbulators in the gas side of boiler heating surfaces, when excessive stack temperature results from tube-fouling that cannot be remedied by more conventional methods, or from a deficiency of heating surface.

5E. 3 REFRIGERATION PLANTS (EQ-E.3)

Included herein are all types of refrigeration apparatus, both indirect or direct expansion, central or unitary. Related ECOs are referenced at the end of this sub-section.

ECO HR-1-ALLOW HEAD PRESSURE AND/OR COOLANT TEMPERATURE TO REDUCE (EQ E-3b)

Substantial benefits may be achieved by permitting the condensing pressure/temperature (vapor-compression cycles) or coolant temperature (absorption cycles) to drop as the ambient db/wb temperature reduces.

1. Vapor-Compression Cycle

1.1 The $85^{o}/95^{o}/105^{o}$ syndrome is unfortunately rigidly adhered to by many, who fail to realize the benefits in energy attainable as ambient temperature drops. This occurs by permitting the 105^{o}F refrigerant condensing temperature (CT) and 95^{o}F leaving water temperature (LWT) to drop when the chiller operating characteristics permit it.

1.2 The HP/Ton ratio of a vapor-compression cycle decreases dramatically when its pumping head (condensing pressure minus suction pressure) decreases. When a cooling tower can deliver substantially less than 85^{o}F entering water temperature (EWT) to a condenser, it is not justified to cycle tower fans or pumps, or to engage by-pass valves to keep the CT at 105^{o}F. It is not likely for the pump or fan HP savings to exceed the saving from HP/Ton reduction, achieved by leaving them running to drop the CT and the pumping head of the refrigerant cycle. This is especially true, when the forced high CT is maintained by tower bypass control, with full fan and pump HP.

1.3 The CT in any cycle should be permitted to drop to the lowest tolerable point of expansion valve or chiller metering valve operation. Each machine's characteristics should be checked, and the head pressure control point set to maintain that low limit - 105^{o} F or some other arbitrarily high setting. Taking advantage of this, normally requires no more than re-setting the head pressure or the temperature controls.

1.4 The low limit of condensing temperature or pressure is governed by the refrigerant valve pressure drop requirements. The reduction in CT can be as much as 20^{o}F degrees with performance increases from the customary 1 Ton/HP to as much as 1.5 Ton/HP in comfort refrigeration cycles.

2. Absorption Chillers

Even the older chillers that required the use of tower by-pass valves, customarily set at 85° F EWT, have considerable tolerance to lower temperatures before accidental crystallization occurs from overconcentration of the liquor. With appropriate trimming, the EWT can be as low as 70 °F on some older chillers. Newer absorption chillers can tolerate EWT as low as 45 to 55° F and do not even require by-pass valve controls (depending upon the manufacturer). When the EWT is permitted to float with the ambient condition, the steam rate (lbs steam per hr/ton) is markedly reduced.

3. Evaluation of Energy Saving

Whether the specific machine is reciprocating, screw, centrifugal or adsorption, the actual magnitude of improvement is a function of its specific performance characteristics, which must be checked. In addition, the manufacturer should be consulted on possible operating problems, if the intended operating points fall outside the published range of performance values.

ECO HR-1.1 MAINTAIN MINIMUM CT BY CLEANING AND PURGING (EQ-E.3c)

To maintain the best performance at any given EWT, condenser water tubing must be kept clean and the refrigerant side must be kept free of non-condensables. From a maintenance standpoint, the cost of high condensing pressures resulting from presence of noncondensables, tube-fouling, dirty strainers, poor cooling tower performance, and poor water treatment is too high a penalty to ignore. Some plants whose refrigeration operation cannot even tolerate the time for shut-down tube cleaning employ "on-line cleaning" with automatic reverse flow (backwash) at perodic intervals. (See ECO 0-3, Section 5L).

ECO HR-2 KEEP CHILLER LEAVING WATER TEMPERATURE(LWT)HIGH(EQ-E.3a)

Unnecessarily low chilled water temperatures are also an energy drain, for the same reason as above (i.e. improved HP/Ton ratios or reduced steam rate). Raising the chilled LWT raises the operating suction temperatures (ST) and reduces the chiller work load. Evaluation of the energy benefits are made in the same manner as described above. In both cases, the reduced energy input per ton-hour output is applied to the annual ton-hr energy node, determined in Chapter 3 for the actual building.

ECO HR-2.1 SCHEDULED CHILLER LWT CONTROL

Both full load and part load LWT may be too low. Field trial and error testing, following engineering analysis, permits trimming the temperature to the highest tolerable temperature which meets the required conditions of leaving air temperature (LAT) and/or room humidity control. Many installations and designs can tolerate a substantial spread between full load LWT and part load LWT. When a spread is permissible a number of techniques may be applied to control the LWT:

- LWT may be scheduled automatically from outside air (OA) temperatures (within set limits) to take full advantage of sensible heat load reductions, with override, if necessary by room humidity.
- The scheduling can originate from a sensor which monitors the system part load condition. This may be effected in systems using cooling coils with valve control, by picking up a signal from a select number of valves (or all valves, when necessary) which sense reduced coil loads. For systems using coils that have no valve control, reduced load can be sensed by reduced LWT off the coil. In both cases, the reset of chiller LWT may be overcalled by room high limit humidistat(s) which should be set at the highest tolerable condition.

If one or more air systems in a common chiller circuit have a common dew point or dry bulb leaving air temperature (LAT) control, then the benefits of higher chiller LWT control can be increased by raising the coil LAT set point as the load decreases. In the case of reheat or dual path systems using LAT control, reduced system loads may be sensed by ambient conditions or room thermostat signals (in lieu of coil valve signals), again with necessary room humidity overcall. The increased benefits derive from the replacement of parasitic reheat energy with reduced chilling, which reduces both refrigeration and reheat energy requirements. (See ECO HA-3.1 and ECO HA-3.2).

If it is assumed that the acceptable fan LAT might vary from 55° F to 68° F, with proper high-limit humidity control during occupied periods, then whenever the ambient wet bulb temperature is low enough to avoid room humidity overshoot, the refrigeration can be shut down. This can happen during many hours of operation between ambient dbt conditions of 55° F and 68° F. Direct sensing of these needs by the governing room conditions takes optimum advantage of low enthalpy weather conditions, which could not otherwise be accomplished with once-through systems (i.e. conventional enthalpy control for once-through OA systems is useless, since choice between outside and return air is non-existent).

ECO HR-3 OBTAIN REFRIGERATION AT REDUCED ENERGY INPUT (EQ-E.3h)

A number of methods are available for both centrifugal and absorption chiller cycle retrofit. These permit reduced chiller capacity to be obtained at ambient conditions below 50 to 55° F, without running a centrifugal compressor; or, in the case of an absorption chiller, without the use of input steam, in one method, or with only a small percentage of normal steam, in another method.

These techniques are only feasible when, (a) chilled water is required for a substantial number of operating hours per year below an ambient temperature level of 55° F dbt; (b) the air conditioning units or other terminal apparatus are unable to use direct outside air supply; (c) the refrigeration loads below 55° F ambient are not greater than 35 to 60% of design full load, depending upon which method is used and other specific job conditions. The systems are proprietory and are marketed under the following names:

a. "Thermocycle" - for centrifugal refrigeration compressors - is a closed system which pumps the refrigerant through the evaporator, chilling the system water. The refrigerant vapor is then cooled by migrating to the condenser, where condenser water is cooler than the chilled water. Since condenser water can be cooled to within a few degrees above the ambient wet bulb, and since the wet bulb temperature averages approximately 7° F lower than the ambient dry bulb, then 50° F or lower chilled LWT is usually available through this Thermocycle heat exchange.

b. "Strainer Cycle" - for absorption chillers - is an open system which uses cooling tower condenser water directly in the chilled water circuit. With proper straining and chemical treatment suitable for such an open coolant circuit, the principle is similar to that of an open air washer (evaporative cooler). This coolant, however, flows through the chilled water piping system and coils, while in a refrigerated air washer system the coolant circulates through the chilled water piping system and a spray conditioner. Comparing the Strainer Cycle with the Thermocycle, at a 55°F ambient dbt/48° F wbt, the Strainer Cycle can produce approximately 50% of full load cooling with 50°F tower LWT, while the Thermocycle can produce approximately 35% with the same 50° F tower LWT and 58° F chiller LWT.

c. "Therma-Gain" - for absorption chillers - is a closed system, similar to the Thermocycle, using a liquor pump and cooling water to cool the chilled water. Its performance, however, differs in two respects;

(1) It cannot cool the chilled water stream as low as either the Thermocycle or Strainer Cycle, requiring for example, 44° F wbt to produce 35% full load chilling.

(2) It requires a small stream input to avoid over-concentration and crystallization of the bromide solution. This input steam rate varies from 17% of that required under normal summer operation at 10% load, to 3% steam at 60% load.

(3) It cannot be retrofitted and must be purchased as a feature in a new chiller only.

RELATED ECOs IN OTHER SECTIONS OF THIS CHAPTER

ECO HR-4 EFFECT OF VARIABLE SPEED PUMPING ON CHILLER PERFORMANCE - Refer to ECO HCH-1.1, Section 5E.7

ECO HR-5 HEAT PUMP SYSTEMS - Refer to ECOs WH, Section 5K.1

5E.4-STEAM DISTRIBUTION SYSTEM (EQ-E.4)

This ECO classification includes the distribution, and in some cases the control and utilization, of steam within a building.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO HS-1 SYSTEM PRESSURE REDUCTION - Refer to Site ECO S-10

ECO HS-2 CONTROL OF STEAM SHUT-OFF TO SELECTED ZONES OR BRANCH MAINS
Refer to Site ECOs S-11 & S-12. The principles covered in these Site ECOs for application to entire building and site distribution branches apply equally as well to building sections, zones or branch mains.

RELATED ECOs IN OTHER SECTIONS OF THIS CHAPTER

1. Refer to Section 5K.1,ECOs WH for HVAC Recovery System
2. Refer to Section 5K.5, ECO WLK for Energy Leakage and Loss
3. Refer to Section 5J, ECOs M for Control.

ECO HS-3 ELIMINATE OR FIND ALTERNATE HEAT SOURCE FOR RESIDUAL LOADS

A profile study of steam usage during low building load periods, may reveal that the requirements of one or two utilization devices constitute an insignificant portion of full load steam demand. If the annual hours of operation under such low load conditions are coupled with a need to keep extensive portions of a steam system alive, and the piping layout does not lend itself to shut-off of major unloaded mains, then this ECO should be examined. Some possibilities are illustrated:

1. Summer Reheat

   Reheat control can frequently be eliminated by substitution of variable air volume (VAV), at least as a first stage of cooling reduction. Even applications which have high-limit humidity requirement can frequently tolerate the elimination of reheat during the warm, dry weather periods. If such reheat is the only summer steam load, extensively distributed throughout a building, then substantial savings are possible by its elimination during these periods. Detailed evaluation is similar to the procedures shown in the SITE ENERGY REPORT for pipeline losses and for heating/cooling energy savings in ECO HA-1, Par. 2.

2. Substitute Energy Source

Identify any residual steam loads which are required during mild weather conditions, are concentrated at one or two locations and can be satisfied with a seasonal alternate energy supply. For example, if the sole existing steam load(s) are from service water heaters with a light demand, then replacement with off-season electric heating may conserve more source energy (by the elimination of widespread steam distribution losses) than is required for the electric heating.

5E.5-CONDENSATE RETURN AND FEEDWATER SYSTEMS (EQ E.5)

This ECO classification includes energy nodes for all portions of a steam system which are in liquid phase, before or after the generation of steam. Related ECOs described in the SITE ENERGY HANDBOOK and in other sections of this chapter are referenced below.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO HCR-1 CONDENSATE LEAKAGE - Refer to Site ECO CR-1
ECO HCR-2 INSULATION - Refer to Site ECO CR-2
ECO HCR-3 PUMPING SYSTEMS - Refer to Site ECOs W-1, W-3, W-5 & W-6

RELATED ECOs IN OTHER SECTIONS OF THIS CHAPTER

1. Refer to Section 5G, ECO P for pumping
2. Refer to Section 5K.1, ECO WH for HVAC recovery
3. Refer to Section 5K.5, ECO WLK for energy leakage

ECO HCR-4 AVOID FLASH LOSSES

The magnitude of flash loss from atmospheric vented vessels which contain saturated water (i.e. at 0 psig and 212 F) is a function of the pressure and temperature (P/T) of the condensate flowing into the vessel. Figure HCR 4-1, from Reference 14 shows the condensate lost as vented steam for various saturated condensate pressures.

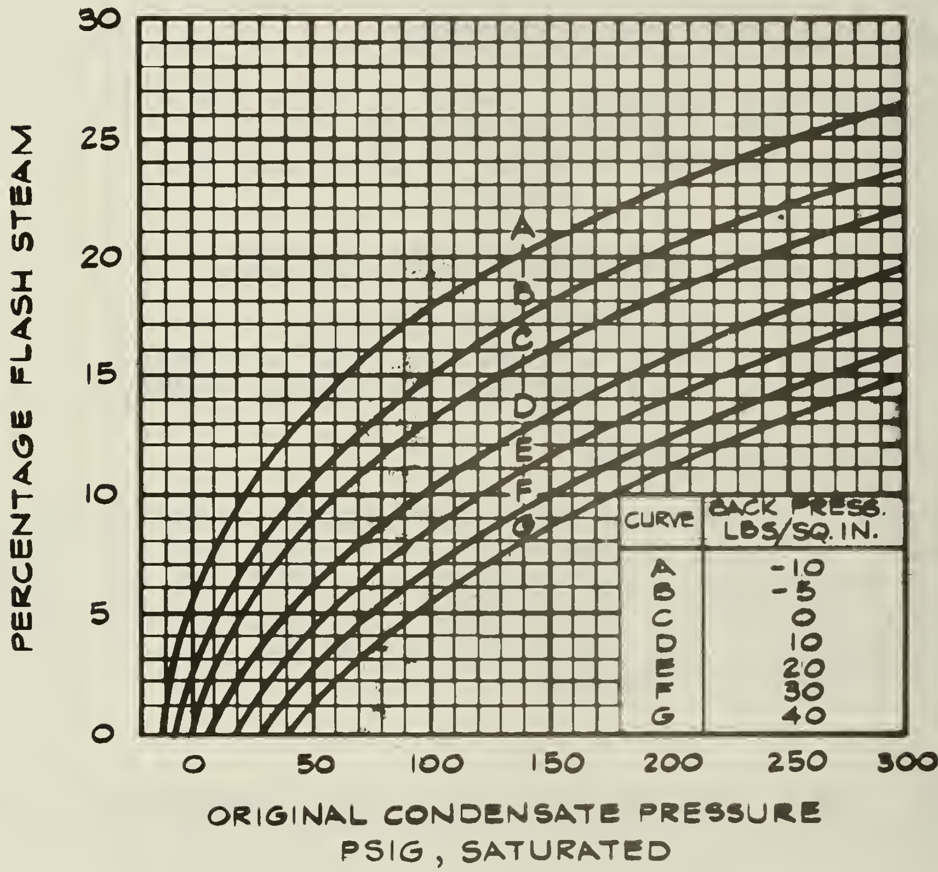
ECO HCR-4.1 INJECT COLD MAKE-UP WATER INTO CONDENSATE RETURN TANK

Figure HCR 4-2 shows how make-up water required by a steam generating system can be injected into the vent of a condensate return tank to condense the flash steam and reduce the vent losses. If the quantity of make-up required is always adequate to reduce the tank contents to below 212°F, then this is a positive means of eliminating flash loss. Several observations apply:

a. Only specially designed pumps can handle condensate at or near saturated pressure. Conventional condensate pumps of centrifugal or vane type design have difficulty handling condensate above 180°F without vapor binding. Therefore it is desirable to cool a receiver to this temperature, if it can be accomplished without flash loss.

FIG. HCR 4-1
FLASH LOSS VS CONDENSATE PRESSURE

PERCENTAGE OF FLASH STEAM FORMED WHEN CONDENSATE AT VARIOUS STEAM PRESSURES IS DISCHARGED TO VARIOUS BACK PRESSURES.



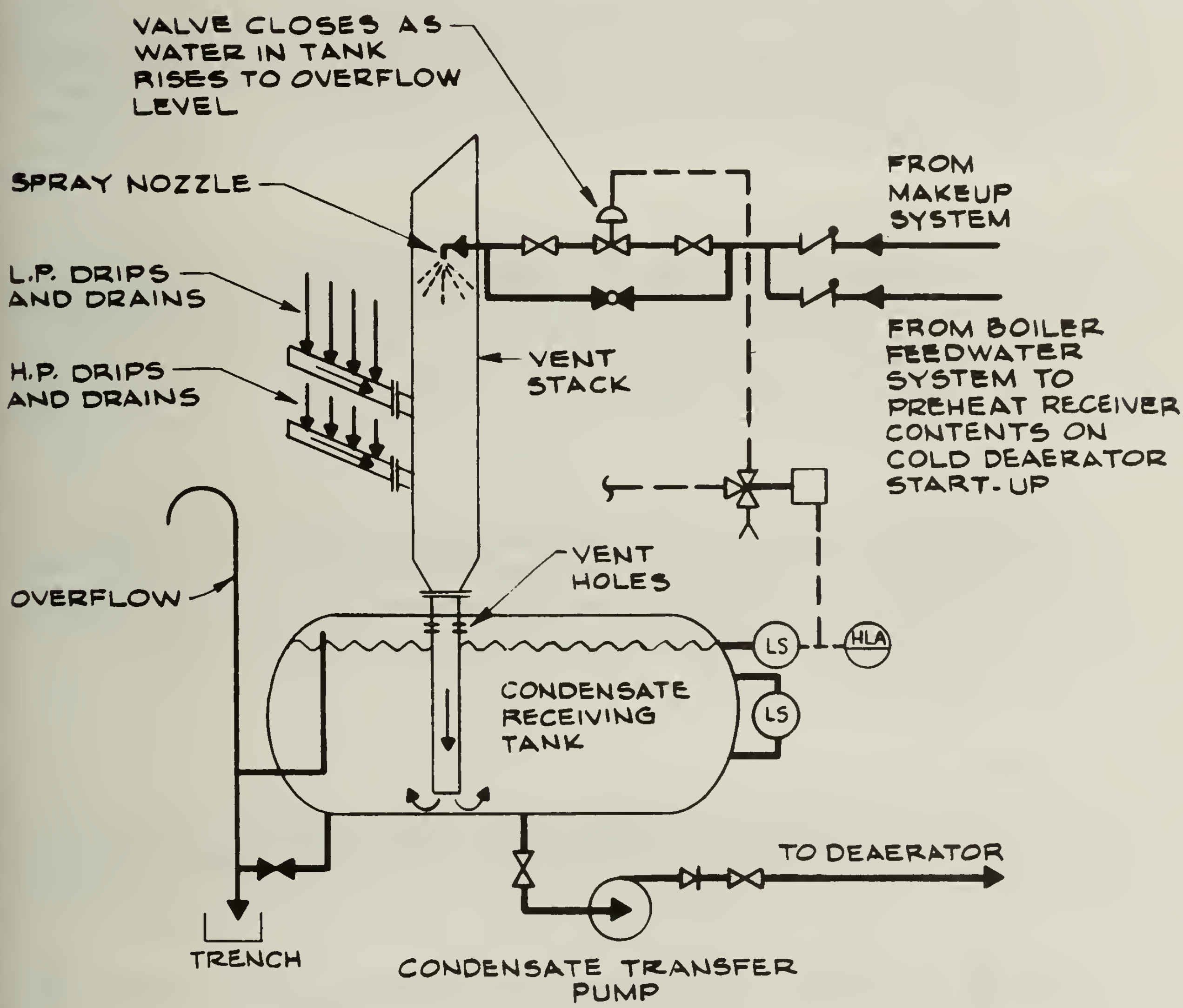
FOR AN EXAMPLE, ASSUME A CONDITION IN WHICH 20,000 LBS OF CONDENSATE PER HOUR ARE BEING RETURNED FROM PROCESSING EQUIPMENT OPERATING AT 100 PSI TO A RECEIVER WHICH IS VENTED TO ATMOSPHERE.

FIRST FIND THE PROPER CURVE ON THE CHART. THE INSET TABLE SHOWS THAT FOR 0 PSI- A VENTED RECEIVER- WE SHOULD FOLLOW CURVE C. (IF CONDENSATE WERE DISCHARGED TO A BACK PRESSURE OF 30 PSI WE WOULD FOLLOW CURVE F).

LOCATE 100 PSI ON THE HORIZONTAL BASE LINE. FOLLOW THIS UP VERTICALLY UNTIL IT INTERSECTS CURVE C. NOW READ THIS POINT ALONG THE LEFT HAND VERTICAL AXIS - APPROXIMATELY 13%.

OUR ANSWER, THEN IS 2600 LBS OF CONDENSATE (13% OF 20,000 LBS) FLASHES INTO STEAM WHEN CONDENSATE FROM 100 PSI PROCESSING EQUIPMENT IS DISCHARGED INTO A RECEIVER VENTED TO ATMOSPHERE.

FIG. HCR 4-2
INJECTION OF MAKE-UP INTO CONDENSATE RETURN TANK



For condensate returned at substantially 0 psig, saturated, cooled to a final tank temperature T_t, with make-up water at temperature T_m, the percent make-up flow to condensate flow (before mixing) is $(212 - 180^\circ)\ 100 / (212^\circ - 60^\circ) = 21\%$.

b. The cool make-up water should be treated to a quality equivalent to that required at the heat generating plant. If the condensate tank involved is remote from the plant (e.g. at another building) then this quality of treated water is usually not available. It is not good practice to employ untreated water for this purpose, since the corrosion and operating problems resulting from such use may be a greater disadvantage than the savings in energy.

c. If the make-up rate is low in relation to the P/T of return condensate, then too many hours of operation during which cooling is inadequate will render this technique relatively ineffective. In most steam systems, the percentage of condensate return/steam produced increases at part loads, since leakage tends to be constant unless steam is directly injected into utilization apparatus or just not returned from others). Consequently, in the former case, a calculation of the quantity of make-up required to cool a given P/T of condensate returned at full load will permit an evaluation of this method's feasibility, when it is not currently in use. The following heat balance applies whenever the return condensate is above 0 psig saturated.

$$Q_{cr}\ (h_{cr} - h_t) = Q_m\ (T_t - T_m)$$

where:

Q_{cr} = Condensate return flow, lb/hr
h_{cr} = Enthalpy of condensate @ P/T of average hot return, Btu/lb
h_t = Enthalpy at final tank temperature, Btu/lb
Q_m = Make-Up flow, lb/hr
T_t = Final tank temperature desired, $^\circ$F.
T_m = Original temperature of cool make-up, $^\circ$F.

d. When this type of injection is currently being used, observation of the extent of vent vapor losses will permit a determination of its effectiveness.

ECO HCR-4.2 CONNECT HPS & LPS FLASH VESSEL VENTS TO LPS LOADS

All flash vessels which are presently vented should be repiped into LP or MP steam lines which are active and close by. Provisions shall be made for atmospheric relief when the lines selected cannot absorb the flash vapor. This ECO is applicable to such vessels as flash tanks and direct-contact deaerators.

ECO HCR-4.3 INSTALL VENT CONDENSER ON FLASH VESSELS

When neither ECO HCR-4.1 or 4.2 is applicable, consider the installation of a vent condenser to recover all the heat of vaporization. If the coolant source is adequate and positive in availability, then most of the vapor heat content as well as its condensate may be recovered.

ECO HCR-4.4 INSTALL PUMPING EQUIPMENT THAT CAN HANDLE HOT CONDENSATE

When none of the above ECOs apply, pumping equipment and techniques are available to either pump condensate directly back from the load into a boiler (without going through a condensate tank) or to take suction from an unvented receiver with no flash losses.

In the first category (References 15, 16) are special pump assemblies which are designed to handle hot condensate in mixed phase (i.e. liquid and vapor). They are often used on large-load units such as absorption chillers (in parallel with the conventional vented receiver return from other loads). They cycle with the chiller, and are especially useful when the elevations of the chiller and receiver would not permit gravity return in the condensate receiver.

The second category includes "pumpless" return systems (Ref. 15) that alternate a condensate fill cycle into the unvented receiver with a steam injection cycle,in a manner that permits the steam to empty the receiver's contents into the boiler.

ECO HCR-5 REDUCE FEEDWATER (FW) PUMPING POWER REQUIREMENTS

High pumping pressure requirements of medium and high pressure boilers, together with the normally wide swings in FW flows as loads vary, provide a number of ECOs for consideration. Analysis and calculation techniques have been presented in the SITE ENERGY HANDBOOK, but this section describes the nature of some opportunities.

ECO HCR-5.1 REDUCE DISCHARGE PRESSURE OF FEEDWATER (FW) PUMPS AT FULL LOAD

FW pumps are frequently installed with excess head in specific installation situations, for such reasons as overdesign and lowering of rated pressure or capacity of a boiler plant. The maximum operating discharge pressure should be no greater than that required to deliver actual plant full load flow (allowing for surge demand or cold startup), with all FW supply system valving wide open. The pressure at the inlet of the FW control valving, under this condition should be higher than the operating boiler pressure as required by control stability and the pressure drop (P.D.) from the FW to the boiler drum. Thus, an excessive pressure drop in the FW supply, either from unnecessary throttling or from an undersized valve, imposes a permanent parasitic energy load upon the pumping system.

This condition of excess head at full load can be remedied in the case of steam turbine driven FW pumps by setting the governor at an appropriately lower speed, after reducing excessive FW valve P.D. This can be done without valve hunting by installing another valve in parallel with the existing one, to permit stable control at low loads. If a motor drive is used, the pump impeller can be shaved. Refer to SITE ENERGY HANDBOOK, ECOs W-1 (including Site References 46 and 47), and W-5 for further details. This ECO results in savings in the pumping system at full load, but does not take advantage of savings possible at reduced plant and pumping loads.

ECO HCR-5.2 LET PUMP ENERGY FOLLOW THE PLANT LOAD

The FW pump flow requirements are directly proportional to the steam load, while frictional P.D. losses in the FW pumping circuit vary with the square of the flow. There is no reduction in the FW pump head component which represents the boiler pressure. As the boiler operating pressure increases, the P.D. component becomes a less significant portion of the total pumping energy. But, with an economizer in the FW supply of a 200 psig boiler and a 150 lb loss in the piping system, it could still represent considerable energy.

With a steam turbine drive, a fixed speed governor can be replaced with one whose speed control point can be reset by a P.D. controller that maintains a fixed P.D. across the last FW control valve. As FW flow drops, this control permits the pump to "see" the piping P.D. reduction and reduce the pump speed for minimum energy input. An illustrated solution to such an energy analysis in shown in Fig. HCR 5-1 taken from one of the multi-stage FW pump curves, assuming two operating modes, for full load and 50% load:

a. Full load: Boiler 220,000 lb/hr, steam @ 200 psig(463 ft)
Pump - 440 gpm @ 880ft TDH

. FW control valve, wide-open P.D. (assumed)	=	25 psi	=	57 ft
. Piping system P.D. at full load	=	155 psi	=	360 ft
. Total FW system P.D. at full load	=	180 psi	=	417 ft
. Boiler drum pressure	=	200 psi	=	463 ft
. Total pump TDH		380 psi	=	880 ft

b. Constant speed pump: 3550 RPM

. Point (1) rated full load 440 gpm, 880 ft TDH, 170 BHP

. Point (2) 50% flow 220 gpm, 990 ft TDH, 115 BHP

c. Variable speed pump: reduced speed for 220 gpm flow

. Line (3)= pressure of steam + fixed valve P.D.
= 463' + 57' = 520 ft

. Point(4)=(3) + Full load piping P.D. x $(220/440)^2$
= 520' + 360' (0.25) = 520 + 90 = 610 ft

. BHP at reduced speed, 220 gpm, 610 ft TDH = 68 BHP

d. Power saving from full load at 170 BHP:

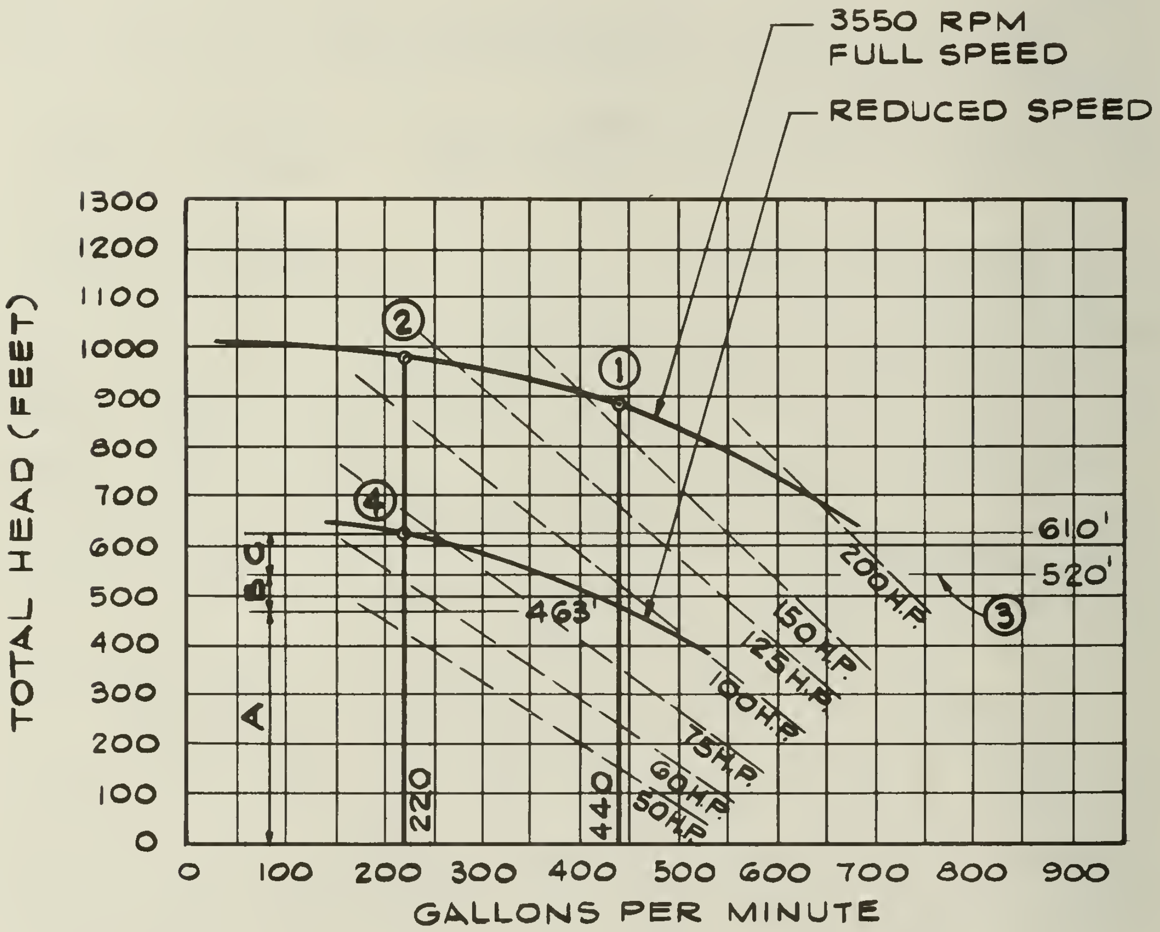
. at reduced speed: (1)-(4)= 170 - 68 = 102 HP or 60%

. at constant speed: (1)-(2)= 170 -115 = 55 HP or 32%

. or increased savings with variable speed pumping (VSP) 47 HP or 28%

FIG. HCR 5-1

FW PUMP CURVES-VARIABLE VS CONSTANT SPEED



A- BOILER PRESSURE 463 FT.

B- VALVE P.D. 57 FT.

C- PIPING P.D. 90 FT.

e. This power reduction can be viewed as representing the savings for a reduction of 110,000 lb/hr steam load (i.e. 50% of 220,000). If a plant load factor were such that a 110,000 lb/hr average reduction in load occurred over an annual period, then this additional saving could represent 47 hp x 8760 hrs/yr or 410,000 hp-hrs/yr per 110,000 lb/hr average load reduction below plant full load. This can be translated into lbs steam or Btu of fuel for cost savings. Conversion factors will be dependent upon particular conditions of heat balance at a plant. For example, if a 200 psi FW pump turbine's exhaust were 100% utilized at 5 psig, then the incremental power charge for pumping is only 1200 Btu/lb (at 200 psig) - 1156 Btu/lb (at 5 psig) or 44 Btu/lb steam at the throttle. If the exhaust steam could not be utilized each lb at the turbine throttle should be charged with the full Δh at the boiler.

Multiple pumps, headered for common pumping to a multi-boiler installation can be sequenced automatically, whether motor or turbine driven, from the same type of fixed FW control valve P.D. sensor, after an analysis is made of the cut-in and cut-out points required to avoid short-cycling.

Motor driven FW pumps can be converted to VSP as indicated in the previous Site ECO references.

The savings increase dramatically with VSP or pump sequencing, if the existing FW pumping system is one which by-passes the flow not required by the plant at the full load flow, or at some selected, relatively frequently reached, reduced flow condition. Analysis technique as illustrated above can be extended for this condition.

5E.6-HOT WATER DISTRIBUTION SYSTEMS (EQ E.6)

This ECO classification includes energy nodes for all hot water recirculation systems in comfort and process applications. Once-through, service hot water systems are covered under Section 5F.1 of this chapter. Related ECOs described in the SITE ENERGY HANDBOOK and in other sections of this chapter are referenced below.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO HHW-1 BY-PRODUCT HOT WATER - Refer to ECOs S-1, 2, & 3

ECO HHW-2 CONVERSION OF STEAM TO HW- Refer to ECO HW-4

ECO HHW-3 INSULATION MANAGEMENT - Refer to ECO S-7, 8, & 8.1

ECO HHW-4 LOWER TEMPERATURES & RAISE DIFFERENTIALS - Refer to ECO HW-7

RELATED ECOs IN OTHER SECTIONS OF THIS CHAPTER

1. Refer to Section 5G, ECO P for pumping also 5E.5, ECO HCR-4.2
2. Refer to Section 5K.1, ECO WH for HVAC
3. Refer to Section 5J, ECO M for control

ECO HHW-5 VARIABLE VOLUME PUMPING

Because of the high inertia heat storage effect of hot water, and greater ΔT between the H.W. and the heated media, better control of heat exchangers for comfort or process is usually attainable when hot water supply (HWS) temperatures are scheduled, and throttling duty of control valves thereby reduced. However where existing system characteristics in both process or comfort applications have shown satisfactory control with 3-way by-pass or diverting valves, then conversion to 2-way throttling control should be considered, since the control effect is the same, all other things being equal. Details of analysis are covered in Section 5G of this chapter.

ECO HHW-6 SCHEDULE HWS TEMPERATURES

For the reason given above as well as the following, the temperature of the HWS should be reset lower, in a predetermined relationship to the system loading:

a. Conduction losses from hot water converters and distribution piping are reduced.

b. Input energy for generation tends to reduce.

c. When design of certain HVAC systems requires heating and cooling to be available on demand for comfort control flexibility, or be simultaneously available in a building or zone, then lower HWS temperatures decreases overshooting of heating capacity and the consequent call for cooling to neutralize the overheat. Also, even without overshooting, scheduling limits the input of heat minimizing simultaneous heating and cooling.

d. When the heating is no longer needed (e.g. at the end of an occupied period) there is less energy to dissipate after heat input is cut off.

ECO HHW-7 CYCLE HOT WATER PUMPS

Certain hot water systems such as those handling perimeter radiation can be cycled by clock-timing for, say, 5 minutes "Off" and 10 minutes "On", at compensatingly higher temperature for each load. The HWS temperature is still scheduled, but to pick up the heating load of the 5 minute "Off" period, its temperature must be slightly higher. The "Off" period can be selected short enough to avoid discomfort at glass areas, effected by the inertia heating from the idle mass of water.

The energy savings even from a 4 kw motor (approx. 5 hp) operating 1500 hrs less in a 4500 hr heating season with a 3 ¢ /kwh cost can save $180/yr, which represents a very rapid payback.

Positive, automatic pump shut-off should be included with such control, to de-activate it at some predetermined outside condition and during non-occupied periods. Below 35°F ambient the pump and hot water generator should be cycled 5 minutes every hour to void freeze-up. Longer "on" periods may be required by

night thermostat setting. Night heating should be conducted at full HWS temperature level - not reduced levels, to minimize pumping costs.

Certain hot water systems may require more positive freeze-up protection than 5 minutes operation each hour. Even air handling coils, directly subject to freezing weather, are fully protected during "Off" cycles of the air handler with outside air dampers closed. Cycling of the pump provides the required additional insurance, without continous operation.

ECO HHW-8 CHANGE SECONDARY PUMPING TO TERMINAL BOOSTING

Identify main building pumps as secondary circulators, connected to site primary distribution loops, or zone secondary pumps which are connected to main building primary loops. Customarily these secondary pumps are piped to be "hydraulically isolated" from the primary loop and needlessly dissipate the residual energy at any primary bridge connection (tap-off point). References 46 and 47 in the SITE ENERGY HANDBOOK describe this ECO in detail, with the energy implications involved when converting from primary-secondary pumping either variable speed pumping, or constant speed terminal boost with pump choking. Instead of using the theoretical techniques described in those references, however, the actual pump curves should be analyzed, with the technique shown in ECO HCR-4.2, which obtains actual hp savings.

5E.7 - CHILLED WATER DISTRIBUTION SYSTEM (EQ E.7)

This ECO classification includes energy nodes for all chilled water circulation systems in comfort and process applications. Once-through, service chilled water systems are covered under Section 5F.1 of this chapter. Related ECOs described in the SITE ENERGY HANDBOOK and in other sections of this chapter are referenced below.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO HCH-1 PUMPING SYSTEMS - Refer to Site ECOs W-1, W-3 W-5, W-6 and W-7. Also see pages 5-59 and 5-60 in this HANDBOOK.

ECO HCH-2 INCREASE TEMPERATURE DIFFERENTIALS - Refer to Site ECO CH.W.-1 and CH.W.-2

The total volume of flow required at full load can be reduced when there is evidence that cooling coils are oversized. The resulting reduction in flow as well as TDH required of the pump, after system rebalance and impeller trim, can effect substantial energy reduction at negligible cost. Field tests can quickly and easily resolve the question of oversizing, by simply checking the results with trial throttling of the main pump discharge valve at high system load conditions. Any evidence of specific coil shortage during such tests should be checked out for system imbalance as the cause before reduced flow is precluded.

ECO HCH-3 RAISE CHILLED WATER SUPPLY TEMPERATURES - Refer to Site ECO CH.W.-2 & Building ECO HR-2.1

ECO HCH-4 DECENTRALIZED LOOP - Refer to Site ECO CH.W.-3

ECO CH.W.-3 in the SITE ENERGY HANDBOOK presents a technique for joining chillers that are not in the same building and not interconnected for parallel or series operation. The principles apply to scattered chillers in a single building as well.

RELATED ECOs IN OTHER SECTIONS OF THIS CHAPTER

1. Refer to Section 5E.3 for refrigeration plant aspects.
2. Refer to Section 5E.5 ECOs HCR-5.1 and 5.2 for full load pump trimming and part load pumping savings.
3. Refer to Section 5E.6. ECOs HHW and Section 5G for other pumping sytem ECOs.
4. Refer to Section 5J for control aspects.
5. Refer to Section 5K.1 for HVAC recovery aspects.

ECO HCH-1.1 VARIABLE VOLUME PUMPING

Unlike HW systems (see ECO HHW-5), chilled water system control is much more stable because of the close approach between the chilled water and the cooled media. Wherever possible, constant volume pumping should be changed to variable volume with the precautions noted below, and in Section 5G. Analysis from actual pump curves is illustrated in ECO HCR-5.2.

Existing constant volume systems which are the easiest to convert are those with 3-way valves, or those with 2-way throttling control that maintain constant pump flow by means of by-pass at the end of the supply main or at the pump. Characteristics and behavior of both in the new mode must be appraised and checked with the valve supplier, but frequently they can be adapted with little or no coil control alteration. Some illustrations follow:

a. If the by-pass lines of 3-way valve circuits have no balance valves, and the control valves are suitable for 2-way use under the system's expected operating conditions, then the by-pass lines must be disconnected and capped.

b. Control stability of the sytem and valve pressure rise ratio (P.D. of valve at shut-off ÷ P.D. at full flow) must be analyzed with reference to a throttling system. If undesirable consequences are likely or found evident with the existing constant speed pumping and control, then a pump choke - controlled from the last coil's control valve P.D.-will alleviate them at minimum expense, with energy benefits from only reduced volume. Variable speed measures will accomplish the same stability at substantially greater investment cost, but with additional energy savings from part load pumping pressure reductions. These measures can also be taken when end-of-main by-passes are eliminated for system as well as coil throttling.

c. Pump by-pass control in existing coil throttling systems can be changed by replacing it with a choke valve or variable speed, again with end-valve P.D. control.

Systems with wild-flow coils (i.e. no control valves) are more costly to convert because throttling valves and associated controls must be added as well. Systems with 3-way valving that cannot be adapted to throttling cause similar complications.

Chiller tube velocity at reduced flow must be checked against the manufacturer's flow vs P.D. charts, to find the lowest acceptable flow for the specific number of passes. This is frequently a much lower figure than is commonly thought possible. Figure HCH 1-1 is a typical set of such curves which illustrates the point. If chiller PCV-IJ, with a nominal 191 ton capacity were selected for the conventional 10F deg. T.D., it would circulate 470 gpm and deliver 197 tons. This 2-pass evaporator could handle as little as 150 gpm at 30° T.D. and deliver 187 tons. This represents a reduction to 32% of full load flow which the manufacturer finds acceptable since his rating curve shows this much variation in flow rate.

Reference 47 of the SITE ENERGY HANDBOOK describes control techniques and ECO HCR-5.2 and Section 5G describe energy analysis techniques.

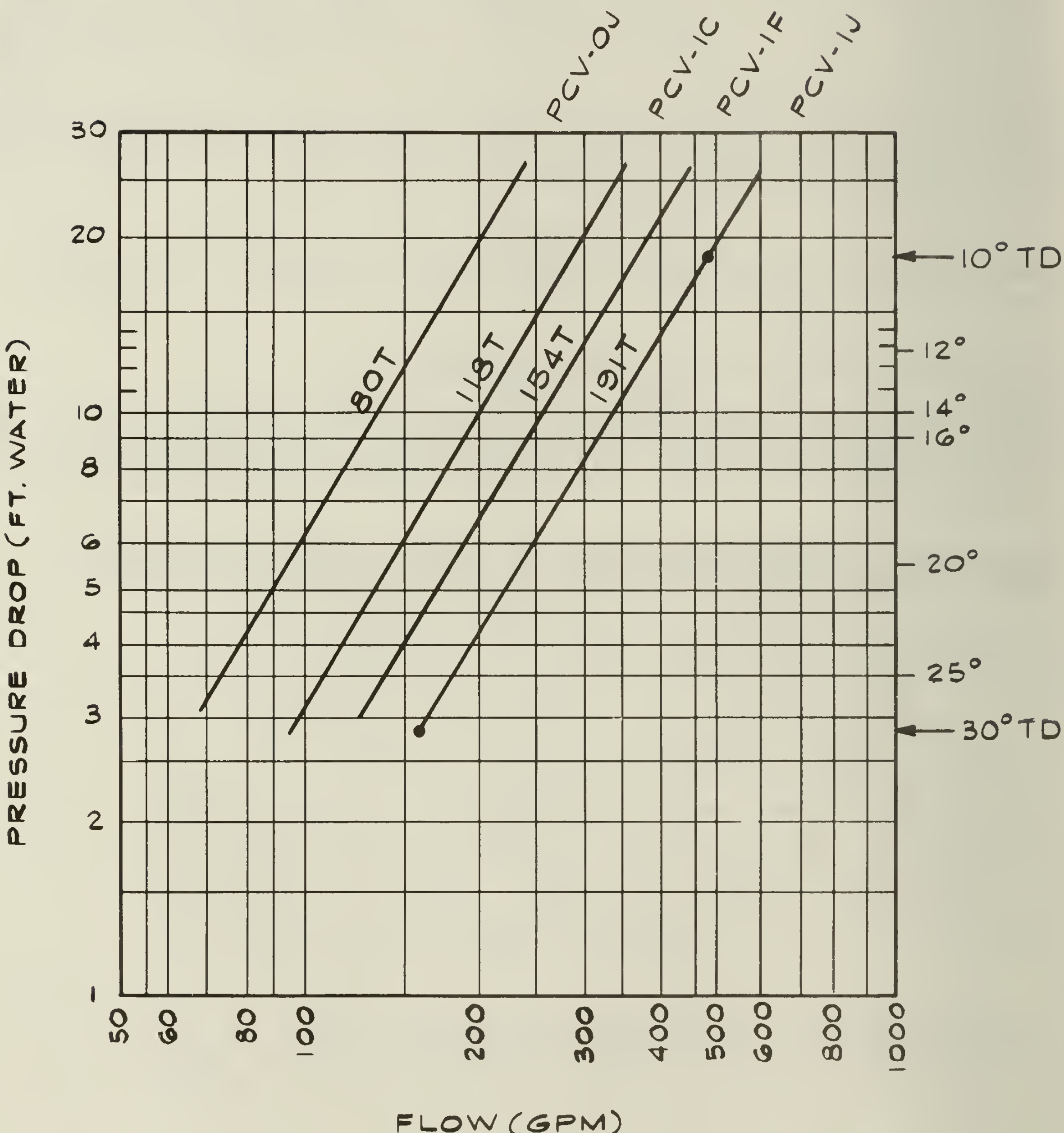
ECO HCH-1.2 PUMP CYCLING AND SHUT-OFF

Chilled water pumps cannot be time-cycled as described for HW pumps (ECO HHW-7), but limited electric load management of pumps is sometimes practical. Automatic shut-off should always be considered.

ECO HCH-1.3 CHANGE SECONDARY TO TERMINAL BOOSTER PUMPING

Refer to ECO HHW-8

FIG. HCH 1-1
CHILLER FLOW VS P.D.



5E.8-AIR HANDLING HVAC SYSTEMS (EQ E.8)

This ECO classification includes all air conditioning systems which use central station air handling apparatus for ducting cool air to many spaces, which may or may not have a supplementary means of cooling. This definition includes All-Air Systems (Reference 6) as well as the air-side of Air-Water Systems and the larger Unitary HVAC Systems. Central station air handlers are generally those which include a fan, a cooling coil, and a means of controlling the cleanliness and psychrometric condition of air leaving the unit. The different types of all-air and air-water systems are described in Chapters 3 and 4 of Reference 6. This Section covers three system types which are often unnecessarily wastefully applied. These are the constant air volume (CAV) dual path, reheat and induction systems.

Another energy intensive node in air systems is the outside air load, particularly for applications which require large amounts of air to replace that which is exhausted. Too frequently, exhaust requirements are a result of outdated, misapplied or unquestioned criteria. Equipment which requires high levels of continuous exhaust, even those which involve safety, should be carefully re-appraised for the application of new concepts and technology.

1. Identification of Energy Wasting Systems and Characteristics

1.1 General

a. Any system which handles the HVAC needs of a number of spaces with different requirements must be wasteful if individual space requirements cannot be met by capacity-controlled supply of energy to the space, accurately proportioned and without simultaneous supply of heating and cooling. Examples of violation of this concept are given below and can only be justified when mandatory end-purposes or result criteria cannot be met in other, less wasteful ways. (For example, a Terminal Reheat System can be considered wasteful when used for room temperature control in normal office space, but not necessarily so when used for temperature/humidity control for process environment).

b. The principles apply whether the media which transports the energy is water, steam, air, chilled or hot water, electricity, fuel, etc.

c. Simultaneous consumption of opposing energy media (e.g. cold and warm air) in conditioned space must be avoided. There are advantages in having opposing media simultaneously available - just so long as they are not coincidentally released into the space, without valid reason.

d. Many of the currently used wasteful systems, provide exemplary comfort conditions in multiple zone applications. This section deals not with these advantages which are well known, but with the wasteful characteristics, and their modification in ways which can offer acceptable standards of comfort or process without the attendant energy waste.

1.2 Constant Volume (CAV) Reheat Systems

a. Reheat may be defined as the addition of sensible heat from any component of the HVAC system, into any zone, for air-conditioning control purposes, when its sole function is to neutralize some of the cooling released into the zone simultaneously.

b. Wherever reheat is employed, modification should be seriously considered.

c. Psychrometric reheat applies whether the heat-source, which releases heat in a space simultaneously being cooled is located in the duct, room or air handler; or whether it is in air flow series or parallel with the cooling air flow.

d. Wasteful psychrometric reheat, whether accomplished by systems known as Reheat, Dual Duct, Multizone or others should not be employed to accomplish either humidity or temperature control except under one or more of the following circumstances.

(1) Non-renewable source heating energy should be permitted as needed for humidity control only for a specific process, health or safety requirement. It should not be employed for ordinary comfort conditioning except with a system and control mode which specifically prevent the conditioned space humidity from dropping below 55 to 60% while such source energy is released to the space.

(2) Recovered energy should be permitted for T/H control as desired, in any space for process, health or safety. It should not be used for ordinary comfort applications for reheat, if at the same time non-renewable source heating energy is being consumed in any portion of the building, even if this portion is served by another system.

d. Source heating energy for the specific control of space temperature is acceptable from an energy conservation standpoint when at least a 50% reduction of each space's design peak cooling load is effected by some means of direct reduction of the cooling energy released to the space, rather than by neutralizing it with heating energy.

This applies to:

(1) Any interior space without exposure;

(2) Any space which is likely to vary its load relationship to any other space served by the same cooling system by more than 25%;

(3) Any space with exposed surfaces. In addition, in this case, the source heating energy should be specifically controlled and scheduled to neutralize skin conduction losses.

1.3 <u>CAV Dual Duct and Multizone Systems</u>

a. Whether blending of warm and cold air occurs at a local dual duct box or at a multizone air handler, if the warm path is activated with a heating coil simultaneously with a mechanically cooled coil, then waste must occur if for no other reason than leakage of cold or warm air through their respective "closed" ports during zone peak heating and cooling requirements. The larger wastes stem, however, from:

(1) Constant volume systems which maintain room temperatures at part load conditions by blending of the warm and cold air streams.

(2) Poorly controlled deck temperatures which aggravate the blending waste.

(3) Imposition of excess heating loads in a warm air stream feeding interior and perimeter spaces from a common air handler. When mechanical or economizer cooling of intake mix air occurs for the purpose of providing cool enough air for interior spaces during heating seasons, unnecessary heating loads are placed on the warm air stream.

(4) When these systems use hot and cold deck coils in a parallel air stream, and no heat is used in the hot deck during summer (or vice versa during heating seasons) then waste is mitigated but not necessarily eliminated.

b. A draw-through fan arrangement on either of these systems, which cools all the air first and then reheats a portion for hot deck blending needs, is one of the most wasteful, since it essentially is in a continuous reheat mode during its entire annual operating period.

c. A common energy disadvantage of all of the above designs is the additional total system supply air which must be powered, compared with single-path systems, in order to provide the sum of the peak air requirements in all zones -- rather than the simultaneous or block peak for the building. The difference can be more than 30% for structures that have high load diversities (i.e. sum of peak loads/peak block load.)

2. <u>Outside Air as a Penalty or a Benefit</u>

a. Outside air can be a benefit or a penalty, as far as energy is concerned, depending upon its use.

b. Enthalpy control in economizer outside air cooling cycles can save many more refrigeration operating hours per year than dry bulb control. But under certain conditions, both can waste more heating energy from poor design or operation than can ever be saved by refrigeration:

(1) A common example of such waste was described in Par. 1.3a(3) &(4) on page 5-65.

(2) Another occurs in systems which use humidification during winter. The accumulated heat of vaporization required for large quantities of winter OA (low humidity air) can sometimes require more source energy Btu's than can be saved from refrigeration.

ECO HA-1 CONVERT CONSTANT VOLUME (CAV) SYSTEMS TO MODIFIED VARIABLE AIR VOLUME (VAV)

1. General

1.1 Many CAV systems can be partially or totally modified to employ the beneficial characteristics of VAV. See Ref. 6. Such conversions must be executed by a skilled designer, with adequate attention given to air terminals of existing installations, the turn-down ratio of throttling and its effect on room air movement, ventilation and the fan characteristics.

1.2 Any modulated reduction of supply air, not accomplished at the throat of an air outlet device(e.g. grille or diffuser) will reduce the outlet's discharge velocity and can be a cause for concern, depending upon the type of outlet, the delivery volume at which it was selected, and the ratio of maximum to minimum air (turn-down ratio). Smaller turn-downs, characteristic of interior areas with relatively small load variations may be treated with less concern than those which suffer large variations (high turn-down). Also air outlets handling small volumes are of less concern than those handling large volumes.

1.3 Outside air ventilation in any VAV controlled room decreases in proportion to the room supply air variation. This factor is mitigated in all-air systems by the fact that air is not recirculated within any specific room, but is mixed in the total supply handled by the particular air handler. This prevents the build-up of odors in any room whose air supply is only a small portion of the total air handler supply. Contamination situations which call for exhaust are no problem with reduced air quantities as long as the supply and/or transfer from adjacent areas is adequately in excess of the exhaust requirements at all times. The balance can be returned to the air handler, when process and safety requirements permit.When no return can be tolerated at any time, as is the case in many laboratory related areas, more sophisticated measures may be considered to permit the use of VAV. These are presented in more detail in ECO HVE.

1.4. Various techniques may be applied to the fan and the outside air control of VAV systems to insure fan and control stability, as well as the continuity of adequate ventilation air as system supply reduces. These include fan discharge or variable inlet vane (VIV) dampers, variable speed fans or variable pitch fans. Generally the choice in retrofit applications is limited, for cost reasons, to discharge and VIV damper control. Energy benefits derive from the resulting fan power savings in varying degrees, in addition to those from heating, cooling and ventilation components.

1.5. True VAV, as intended in these ECOs, must be distinguished from ceiling or return air dumping systems (Ref 6 Pg. 3.16). The latter offers no energy savings.

1.6. System types which may be converted in this context include:

- CAV Dual-path (e.g. dual duct, multi-zone) systems
- CAV Reheat systems
- CAV Induction systems

1.7. Conversions involve either total modification to VAV, when the air volume turn-down at the lowest cooling load condition does not create a ventilation concern; or VAV control in an initial phase, down to a minimum CFM_{SR}, followed by the conventional blending, reheat, or induction cycle inferred in each of the above respective system designs. In all instances, it is the intent of these ECOs to inject no more heating or cooling into any zone than that zone requires throughout its operating range, and to maintain comfort and/or process conditions automatically without manipulation and disruption of the system's operation.

2. Analysis and Appraisal of Energy Savings

The many diverse and complicated energy usage considerations involved in conversions to VAV are much too broad to be handled in a general calculation technique that covers all or even the major types of situations. Sophisticated evaluation is required for each case.

Despite the diversities indicated above, the energy node analysis technique derived in Chapter 3 provides a good point from which studies can originate. They must involve a study of the parameters which make up the present energy consumption, such as reheat, ventilation, etc., and the interrelationships between those parameters in any given air-system under the present and proposed mode of use.

3. Temperature/Humidity (T/H) Control

3.1 Effective conversion presupposes an appraisal of the change in quality, if any, of T/H control. If an expected quality reduction (e.g. rise in high-limit humidity during cooling) is acceptable, as it often is, then the new control program can take advantage of the relaxed criteria to save energy. If it is not acceptable, then the range of turn-down for the VAV phase must be restricted accordingly.

3.2 Overcooling may conceivably offer a problem if a complete conversion to VAV is made (i.e. not followed by warm air blending or reheat) but only individual analysis can determine this. It need never be a problem if VAV is only the first phase of cooling reduction, in the modified VAV cycle.

3.3 In general, considerable throttling is permissible before the room humidity rises to an objectionable value, unless the room load is characterized by high internal latent loads. However even in such case, this only restricts the VAV flexibility of turn-down and only when these latent loads are present, which frequently occurs only during a limited number of operating hours throughout the season. In any event automatic overcall of thermostatic throttling by high-limit room humidity can avoid any problem in such applications. Refer also to ECO HS-3, Par. 1.

4. Fan Considerations

Whenever a CAV system is converted to VAV, the design air supply volume can be substantially reduced - as much as 50%, depending upon the diversity of zone loads. CAV systems need to handle a total quantity equal to the sum of the maxima for all zones, while VAV need only handle the block load. The fan capacity can then be trimmed by a fixed speed reduction at design conditions, while additional year-round power savings are made by reduction of supply, as the block load reduces.

ECO HA-1.1 CONVERSION OF DUAL DUCT (DD) TO VAV (EQ E.8b)

1. Mixing Box Considerations

1.1. Mixing boxes for CAV DD systems are either mechanically or pneumatically controlled to maintain room temperature and room CFM at preset, fixed values. Several box manufacturers market retrofit or add-on devices, which are compatible to their product or those of other manufacturers, for the purpose of converting the box to VAV DD operation.

1.2. Mechanical constant volume regulators (MCVR) maintain set flow regardless of upstream duct pressure fluctuations by utilizing duct system static pressures as an actuating force, while temperature control is independently maintained by pneumatic or electric control of the hot/cold blending. Some existing MCVR devices can be retrofitted with a control motor that permits its setting to be changed within the range of CFM values desired for VAV operation. The first phase of room thermostat control throttles the total air supplied by the box, delaying the admission of hot air until the cold air has been reduced to some allowable predetermined minimum. The thermostat positions the MCVR setting down to this minimum total and the hot port is sequentially opened as the cold port is closed further, at a total constant CFM. In this manner the unit is converted to a mechanical variable constant volume regulator (MVCVR), so designated because at any given setting within a range of variable values, the regulator maintains the set flow volume, regardless of upstream static pressure variations. Another accepted solution to the conversion is to use one MCVR at a fixed, minimum flow setting and a second MVCVR in parallel, for regulation from maximum box delivery to the minimum -- the latter being the fixed setting of the original regulator.

1.3. Pneumatic, electric or electronic constant volume regulators (PCVR) perform both the thermostatic and flow regulation functions by the respective control medium, using a static differential pressure (DP) device for flow control. Otherwise the sequencing and concept of control for CAV and VAV is the same. To convert this type of CAV box to VAV, several options are available:

a. The existing fixed, single setting DP controller can be changed to one which permits its setting to be varied down to the minimum flow volume, if any.

b. The existing DP controller can be employed for the minimum flow condition by manually resetting the pressure differential, while an MVCVR regulator can be added for the regulation from maximum to minimum flow. The mechanical regulator is in parallel air flow with the minimum fixed component, and similar to the previous arrangement is throttled to zero flow before the minimum flow regulator takes over.

2. Full Shut-Off vs. Minimum Air Volume

Certain applications have no minimum air supply requirements, as long as comfort can be maintained without continuous ventilation. This is frequently possible, representing a condition in many unairconditioned homes and commercial spaces without mechanical ventilation but at acceptable T/H levels. Reference 19 and Pgs 3.14 and 3.15 of Ref 6 discuss this subject in some depth. With VAV, such a condition might occur under a no-load condition (i.e. no heating or cooling required), if DD were converted to VAV (no blending), which is possible to do when heating is accomplished by a separate system such as steam or HW radiation. A further benefit of full shut-off capability is that it makes possible the elimination of cooling in unoccupied zones while other occupied zones on the same air handler can be conditioned. This offers considerable economy in applications where small area operations are required during night unoccupied periods.

ECO HA-1.2 CONVERSION OF REHEAT TO VAV (EQ-E.8a)

Existing reheat systems are commonly used for all-air as well as for the air side of air-water systems. (See Ref 6, Chapter 4). In any reheat system, the opportunity exists for reduction of cooling capacity of air systems by an initial phase of VAV reduction before engagement of reheat. Both refrigeration and reheat energy are saved in the process.

Just as for dual path systems, conversion to VAV may be complete (in this case, with the elimination of reheat), or may involve the delay of reheat until after a substantial cooling load reduction has been effected by VAV, down to minimum volume.

Considerations for full shut-off are identical to those for ECO HA-1.1, Par 2.

The VAV conversion may be accomplished in small systems with the addition of direct throttling air devices in certain adaptable air outlets; in larger air systems by mechanical, pneumatic or electric flow controller of the VCVR type, as previously described for DD.

ECO HA-1.3 CONVERSION OF INDUCTION TO VAV-INDUCTION (EQ E.9)

Induction systems rely on a high velocity primary air supply to induce secondary air through a secondary cooling/heating coil in each room to accomplish the air conditioning. The primary air is the subject of this ECO. It is sometimes reheated in the primary air handler or in main zone duct branches covered in ECO HA 1.2. However even when not reheated, it must be recognized that these primary air systems are usually 100% outside air at all times on a constant volume cycle. The primary air is customarily 20 to 30% of the total supply to perimeter areas (primary plus induced air), and is always conditioned. No space cooling can be accomplished without primary air, but the only time that full volume is required for comfort is during design summer conditions. Insertion of a mechanical, pneumatic or electric operated VCVR in the high-velocity primary branch to each induction unit permits primary air VAV control (with simultaneous reduction of induced air).

As primary air is throttled, the secondary induced air is also reduced to a point where some primary air is introduced with a negligible quantity of secondary air. However, since this total reduction is under direct room stat control, it is immaterial, since enough air is admitted to maintain set conditions. In any event, if a minimum supply is desired, then the VCVR may be provided with this capability.

Full shut-off considerations are the same as for ECO HA-1.1, Par 2. Perimeter induction systems can frequently operate for night heating without any primary air at elevated secondary coil HW temperatures (i.e. 180 to 200° F). With VAV controllers on individual units such systems can operate during many winter and summer daytime hours with substantial primary air reductions to complete primary air shut-off, or very low quantities.

Economic evaluation and energy savings are illustrated in some detail in References 17 and 18.

ECO HA-2 REDUCE OUTSIDE AIR (OA) LOAD

When revised criteria, comfort, process and code requirements permit, ventilation should be reduced to the minimum acceptable level for the design condition; reduced further as the occupancy reduces; and cut off when the process requirement becomes zero or area is unoccupied. The following are only some of the steps which can be taken to reach these goals:

a. No system should be operated during unoccupied periods, warm-up and cleaning periods with OA dampers open.

b. Serious consideration should be given to trial and error total shut-down of OA, since many buildings have enough leakage through OA dampers and the building itself to permit such an operation during occupied periods. In the absence of complaints, during periods of energy shortage, this technique should be considered, when it does not disrupt make-up needs for hazardous areas or violate governing codes. The entire issue of actual minimum OA ventilation requirements for normal needs is undergoing critical reconsideration by ASHRAE. A number of public agencies are reviewing their ventilation codes.

c. The OA dampers for morning cool-down periods should not be arbitrarily shut, as in the heating season. The economizer cycle should be used as governed by OA or enthalpy control and even programmed to precool below normal summer set temperatures when possible (i.e. to 70°F on cool mornings instead of to 78°F).

d. Odor absorption equipment in certain high make-up air applications are worth consideration, as are run-around cycles, heat pipes, enthalpy wheels and other heat recovery cycles. Refer to ECO WH, Section 5K. Replace or repair leaky OA dampers. Replace with high quality, tight-closing type. Allow for leakage in minimum OA damper settings.

e. Avoid opening windows to compensate for overheating--look for the reason and rectify.

f. Shut off exhaust fans when not required. Check them for excess over required volume. Reduce exhaust in toilets, laboratories, etc. when acceptable. Automate exhaust fans for shut-down or capacity control, when possible. Refer to ECO HVE.

ECO HA-3 CONTROL DISCHARGE AIR TEMPERATURES

All air systems using fixed temperatures off main heating and cooling coils can benefit by scheduling these temperatures in response to appropriate signals. This measure reduces cooling, heating and reheat energy summer and winter, avoids overshooting of zone temperatures and humidities and minimizes blending leakage losses as well as simlutaneous heating/cooling losses.

Controls can be more or less sophisticated. Computerization of the scheduling, illustrated below can frequently be justified, but more simplified techniques are also possible.

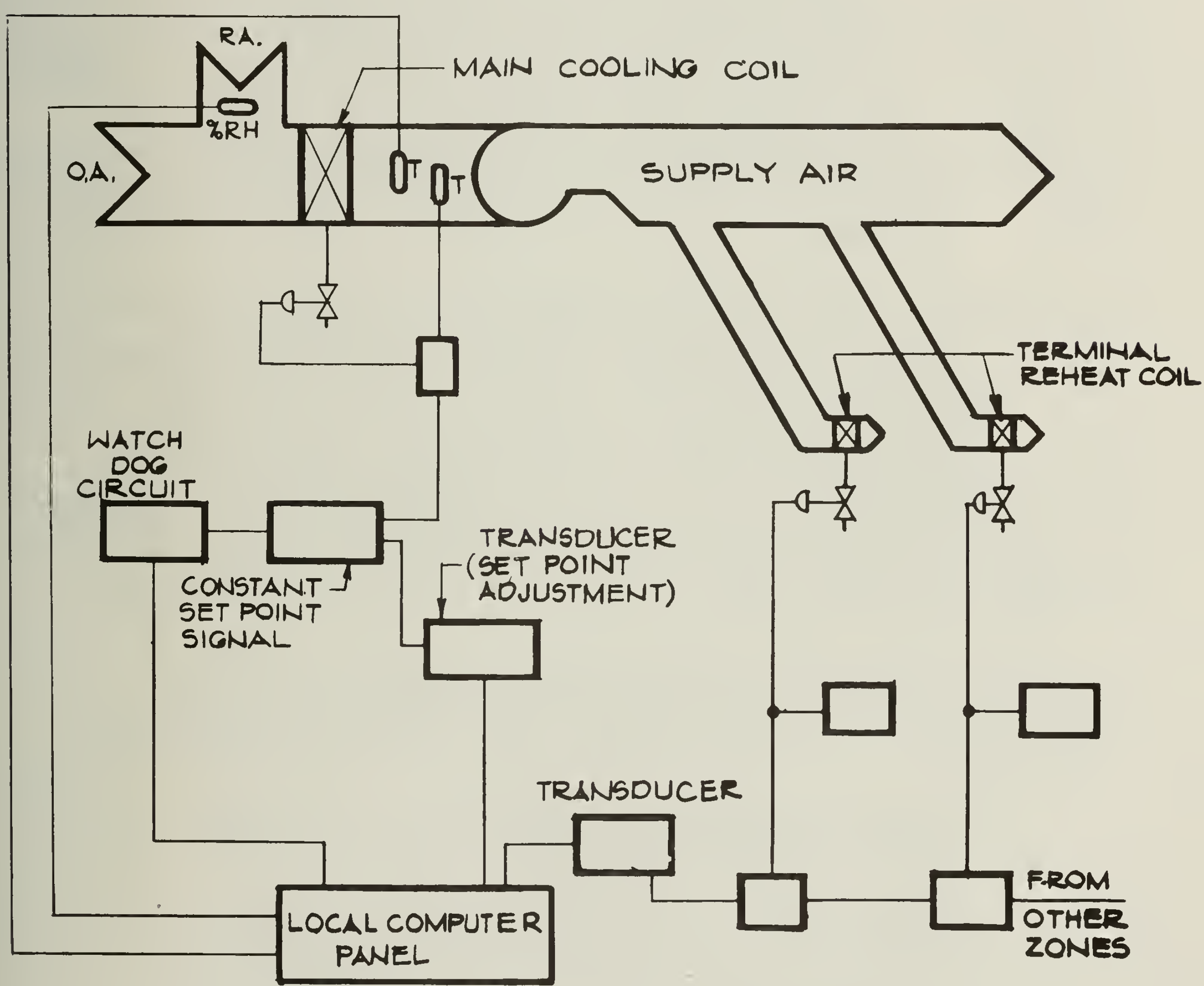
ECO HA-3.1 TERMINAL REHEAT COMPUTERIZED RESET (FIG HA 3-1)

For terminal reheat systems, the Supply Air Reset program receives an input indication of the reduced cooling load. Supply air temperature is then raised according to the amount of cooling used and also the amount of reheat required at the space. Supply air temperatures are only raised within the limits of the humidity requirements as established by the comfort chart and as controlled by return air controller override.

Starting with a room or zone temperature above the room thermostat setting, all reheat valves are shut. When each room has risen to the temperature that signals its reheat valve to start opening, this indicates that the supply air temperature need not be so low. When all rooms are calling for reheat the Supply Air Reset program will raise the supply air temperature 1 F degree periodically. The supply air temperature set point will continue to be raised until at least one room controller begins to call for full cooling; i.e., the reheat coil valve has been positioned to the valve shut-off pressure. A cooling signal (signal greater than valve shut-off pressure) from any zone thermostat will automatically stop any further increase of supply air temperature. Additional increases in cooling demand, from any zone, in accordance with a predetermined value, will result in the Supply Air Reset program lowering the supply air temperature set point 1 F degree periodically. The supply air temperature set point will continue to be lowered until all zone thermostats again call for reheat. When all zones are calling for reheat the process is repeated. The computer is actually in control of the zone with the greatest cooling demand during this period.

FIG. HA 3-1

TERMINAL REHEAT CONTROL FOR DISCHARGE AIR TEMPERATURE RESET



A high limit relative humidity signal in the return air prevents any rise in supply air temperature that would permit excessive humidity within the space.

ECO HA-3.2 DOUBLE DUCT SYSTEM COMPUTERIZED RESET

For double duct systems, the Supply Air Reset program receives both high (cooling) and low (heating) signals from the representative zones, similar to the arrangemment for terminal reheat.

The lowest heating signal is used to control the hot deck at a temperature just high enough to satisfy the space calling for the maximum heating. The highest cooling signal is used to control the cold deck at a temperature just low enough to satisfy the space calling for the maximum cooling. The Supply Air Reset program can reduce hot deck temperature in lieu of increasing cold deck temperature if that is the most economical choice.

To reduce the average relative humidity within the building, the return air dew point will override and readjust the cold deck temperature whenever return air relative humidity exceeds a selected high limit. When the cold deck temperature is at a maximum value and the humidity is still too high (i.e. at very low cooling loads during cool, damp weather) the program can raise the hot deck temeprature to force the zone terminal units to use more cool dehumidified air. However, by comparing total flow in the hot and cold ducts, the program will calculate which duct temperature changes provide the greatest economics. This is true for both the addition and subtraction of moisture.

Because of the large number of mixing boxes in the double duct system, supply air temperature optimization must be done on a selected zone or area basis. The following guidelines apply:

a) Select zones that represent the governing heating/cooling system.

b) Include as many exterior corner zones as possible.

c) Include representative exterior middle and interior zones.

d) Use identical spring ranges for mixing boxes in all selected zones.

5E.9 - AIR-WATER HVAC SYSTEMS (EQ-E.9)

See Chapter 4 of Ref. 3 for detailed description of these systems, which include the perimeter induction system discussed in ECO HA-1.3, Section 5E.8.

Considerations similar to those covered in Section 5E.8 apply to the air supply side of any air-water system, with lesser energy benefit if some of the primary air is recirculated.

For the water side refer to ECO P, Section 5G and other pumping system economy techniques described in this Chapter.

5E.10-ALL WATER HVAC SYSTEMS (EQ-E.10)

See Chapter 5 of Ref. 3 for detailed description of these systems.

Refer to ECO P, Section 5G for pumping systems economies and ECOs HHW and HCH, Sections 5E.6 and 5E.7 for systems using control valves (3-way or 2-way) on the coils of the fan-coil terminal units.

Fan economies should be exercised when possible.

SECTION 5E.11-MULTIPLE UNIT AND UNITARY HVAC SYSTEMS (EQ-E.11)

This ECO classification includes through-the-wall perimeter units rooftop units, self-contained or unitary air conditioners, and closed-loop heat pump systems. Refer to Chapter 6 of Ref. 3 for descriptive details.

These systems are small scale counterparts of the classifications previously covered in this chapter and are frequently a composite of several of them. Some unitary systems, however, are quite large - handling as much load as some of the field assembled and field-piped systems. As such,there are many ECOs in this chapter which apply to the energy components that make up any specific system in this category. For example,any of the ECOs described for the reheat and dual duct systems apply equally to such systems when part of a rooftop conditioner.

5E.12 - VENTILATION AND EXHAUST SYSTEMS (EQ-E.12)

This ECO classification includes the supply of uncooled air as well as the exhaust of conditioned or unconditioned air.

ECO HVE-1 CONVERT CONSTANT VOLUME EXHAUST (CVE) TO VARIABLE VOLUME EXHAUST (VVE)

1. General.

1.1 The economic penalties of once-through constant volume system designs using conditioned ventilation air are well recognized. The safety requirements for applications such as laboratory fume hoods, which prompt this CVE approach, also create the resistance to most efforts at reducing the design exhaust volumes as hood usage decreases.

1.2 Despite the understandable reluctance to involve hazardous and sensitive processes in uncertainties, it is felt that the concept described below, although untried and unproven, merits serious consideration and, perhaps a test run.

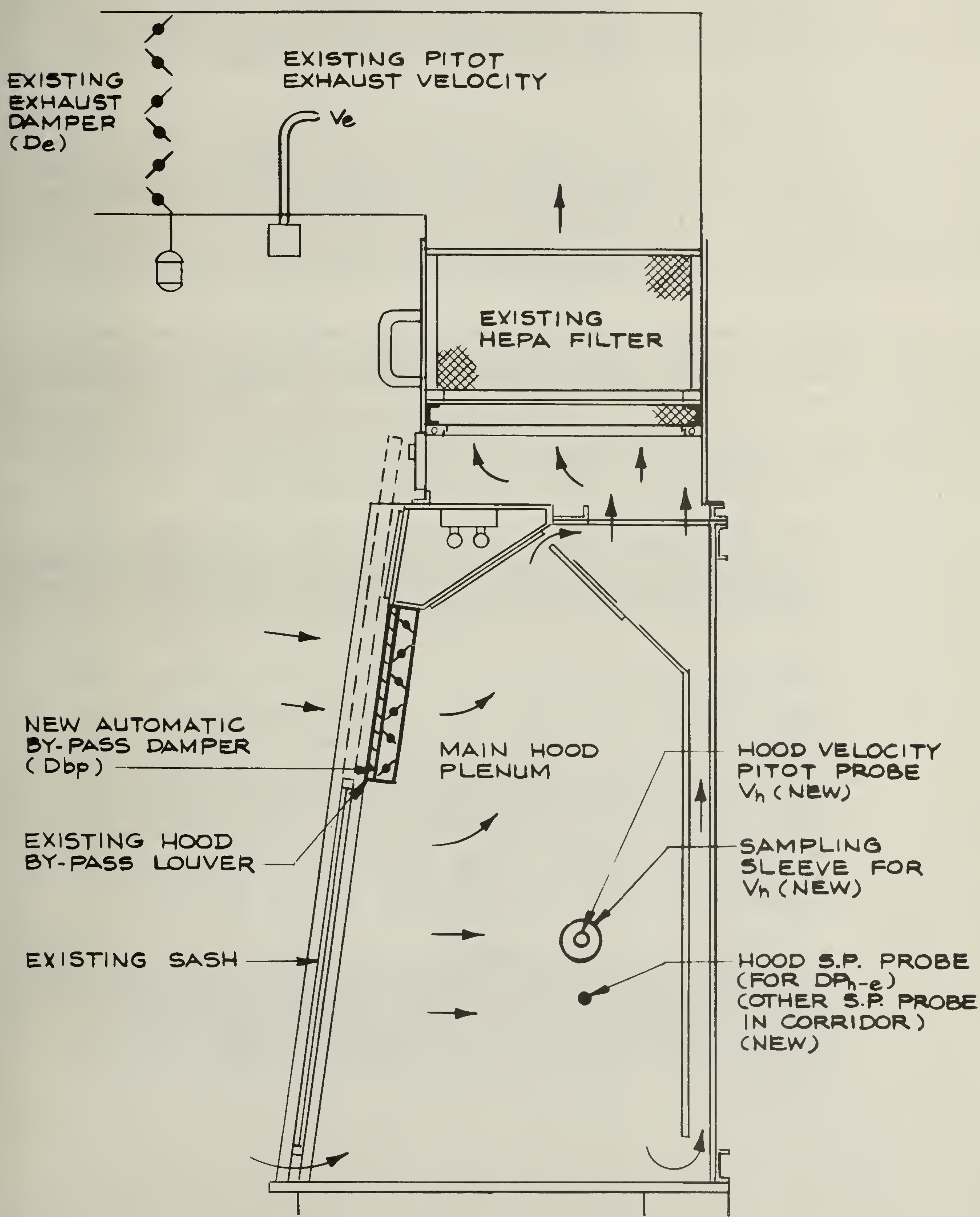
1.3 The proposed concept, which uses the parameters in Building 212 of Argonne National Laboratory-ANL East as a base, is outlined below.

2. Building 212 Background Lab Data (Fig. HVE 1-1)

2.1 Existing fume hoods are mostly the "balanced" type, with 1000 CFM nominal exhaust requirement, fitted with an upper louvred by-pass to maintain constant volume of exhaust within the hood, regardless of sash position. The sash closes fully and the hood has no bottom slot or airfoil. When closed, the entire 1000 CFM enters through the by-pass louvre. Some labs are without fume hoods and were also originally balanced with 1000 CFM exhaust per 12' x 24' module, mostly through conventional canopy hoods.

FIG. HVE 1-1

BALANCED HOOD WITH INTERNAL BY-PASS



2.2 Under current operations, systems have been successfully rebalanced to work with approximately 700 instead of 1000 CFM exhaust from labs with canopy hoods. This was accomplished mainly by eliminating corridor supply, and substituting smaller fan wheels for the ones originally installed in the exhaust fans. Make-up is presently based on CVE operation with each office-lab module receiving approximately 400 to 500 cfm from direct lab supply and 200 CFM transferred from the direct office supply. The average office is supplied with more than 200 CFM, but the portion which is not relieved to the lab exhaust is purged through various other building exhaust fans.

2.3 Existing hood exhaust ducts are fitted with velocity controllers (V_e), primarily for the purpose of maintaining a constant, set exhaust volume as the HEPA filter pressure loss changes. Exhaust damper D_e is under direct control of pitot V_e. A low limit velocity setting of V_e also cuts off all supply air to labs and offices to avoid a radiation spill.

2.4 In the event of a radiation spill and/or a low limit velocity at V_e, most boxes are fitted with an automatic, 2-position damper that shuts off the blended supply air.

2.5 With this description based on a typical dual duct supply system, a module presently consists of one mixing box handling a 12' x 24' lab (previously handled a lab and corridor) and one mixing box handling an adjacent office.

3. Purpose and Requirements of Variable Volume Exhaust (VVE)

3.1 Permit supply and exhaust CFM in each module to vary in response to room thermostat requirements, as long as the hood face velocity, V_h is satisfied (i.e. VAV-DD supply cycle as described in ECO HA-1.1). Room stats must not starve the hood in any sash position. This requires that further SA throttling in lab and/or office be prevented whenever hood exhaust volume at minimum velocity begins to exceed the combined, available SA CFM from lab and office (e.g. hood wide open when cooling load is low).

3.2 Provide the means to exhaust all air which is supplied to any module regardless of the sash position. This requires that the hood exhaust CFM be increased when SA CFM requirements begin to exceed hood exhaust requirements (i.e. hood sash closed with a minimum exhaust of 150 CFM, but with more than a 150 CFM supply air load in lab and office).

3.3 Maintain fairly constant hood face velocity (120 fpm at 1000 CFM, up to a maximum tolerable value -- to be established, but at least as high as 150 fpm).

3.4 When any lab module is unoccupied, no hood experiment in progress and sash is closed, permit the supply of this minimum 150 CFM without regard to thermostatic requirements. A satisfactory means can be implemented to overcall thermostats when sash is closed and occupant wishes to secure the hood. The intent would be to retain thermostatic control at a fixed 150 CFM supply air level, but prevent any increase above 150 CFM, even if stat calls for more air.

4. Proposed Control Equipment Modifications

4.1 Add the following control devices:

a. Pitot probe and differential pressure sensing device (V_h) to maintain the desired sash velocity.

b. Sampling sleeve in front or side of hood to permit unobstructed passage of small air quantity at all times from lab into main hood plenum. Sleeve houses the V_h pitot tube, with minimum turbulence and interference effect from stray air currents and changes in sash position.

c. Automatic damper (D_{bp}) with modulating actuator, set behind existing by-pass louvre in hood, controlled by V_h.

d. Hood-corridor differential pressure control with one S.P. probe in the main hood plenum and one in the corridor (DP_{h-c}). See Par 4.2 and 6.4 of this ECO.

e. Convert lab and office mixing boxes to variable constant volume regulation (VCVR) as described in ECO HA-1.1.

4.2 If necessary, install a differential static pressure control device (DP_{h-c}) to control exhaust damper D_e in lieu of the existing constant velocity exhaust control (not required with VAV). The D.P. probes would maintain a constant negative pressure between the corridor and the hood plenum by controlling the position of D_e. See comments in Par 6.4 of this ECO.

4.3 Add a set of variable inlet vanes (VIV) to the main supply air system fan, which is controlled by the static pressure requirements at the end of the hot and cold supply mains. Whichever one senses a smaller rise from its set point (approximately 1" S.P.) will restrict the VIV to avoid an excess of available pressure at the governing duct.

5. Sequence of Temperature Controls

5.1 Start with room stats in lab and office set at 68° F, in a cool down cycle from room temperature of 78°F. Cold port is wide open, hot port is closed. Flow regulator maintains full load air flow.

5.2 As room cools to 68°F, thermostat resets regulator toward its minimum CFM set point (i.e. approximately 100 CFM for lab and 50 CFM for office). If, for any reason the minimum design SA CFM per module must be higher than 150 CFM, then the minimum hood exhaust will be balanced at a correspondingly higher value.

5.3 Upon reaching the minimum SA setting of the regulator, a further drop in room temperature modulates the hot port open and cold port closed, at constant minimum SA.

6. Sequence of Air Balance Controls

6.1 Start with sash wide open exhausting 1000 CFM at 120 fpm face velocity and assume that the cooling loads only require a total of 500 CFM. The mixing box regulators will therefore be set at a level governed by sash velocity. (V_h would have sensed a drop in velocity if the air supply were below the 1000 CFM exhaust level). Damper D_{bp} is full shut, V_h overcalls room stats to deliver 1000 CFM.

6.2 As the sash is moved toward closure with D_{bp} closed, V_h senses an increase in velocity and lowers the flow regulator settings until they reset to a total of 500 CFM, thereby maintaining the set velocity at V_h.

6.3 As sash is lowered still further, at the 500 CFM supply level now controlled by room temperature requirements, V_h senses a further velocity increase and modulates damper D_{bp} open to maintain the set velocity. Only that portion of the 500 CFM will be exhausted through the sash to maintain the set velocity through the smaller sash opening, while the remainder is drawn through the by-pass damper. If the tolerable velocity range of 120 to 150 fpm previously indicated is valid, the wide control range for V_h will help avoid instability from extraneous local fluctuations.

6.4 As the exhaust reduces from 1000 to 150 CFM, the fan suction pressure increases while riding its performance curve toward shut-off. If the resulting lower hood plenum pressure disrupts the overall module's control stability and/or the required range of operation on the performance curve causes any fan surging, then several solutions are possible:

a. Use the DP_{h-c} controller to position damper D_e for constant negative pressure between hood and corridor.

b. Relocate damper D_e in a new outside air intake leading to the fan suction in the loft area, to act as a by-pass to prevent fan starvation and to maintain a high exhaust stack ejection velocity, if required. Control of the damper is from DP_{h-c}.

c. If the lower ejection velocity at 150 CFM without this by-pass is acceptable, then the same purpose can be served by the automatic damper being placed in a by-pass between the exhaust fan supply and suction.

6.5 In the event of a radiation spill, in addition to the present actuation of total S.A. shut-off, damper D_{bp} opens wide and D_e positions for full fan exhaust from the hood (e.g. open for option 6.4a; closed for option 6.4b).

7. <u>Alternate Instrumentation</u>

7.1 If the constant velocity controller or another mechanical instrument with necessary characteristics is not available, then a hot-wire anemometer device can be used in a similar sampling tube arrangement, to permit air flow in one direction only. Either a simple "flapper-type" gravity damper or a more sophisticated check-valve arrangement will make this possible.

8. <u>Alternative Concept</u>

8.1 The concept, as outlined above, attempts to take full advantage of the potential savings from continuously modulated VAV on a 24 hr/day basis. A simplified alternative involving a two-position VAV modification may be considered, based on the following concept:

a. Institute a procedure which calls for closing the sash of all hoods not in experimental use.

b. Simultaneously, only when separately triggered by the laboratory occupant, reduce the supply and exhaust to some minimum predetermined value such as 150 CFM. This would only be done when the spaces are to be evacuated at the end of the day. At all other times, the air systems would operate on a CAV, CVE cycle.

Thus, during normal occupancy hours, the operator could have the sash in any desired position with a constant 1000 CFM, once-through cycle in effect. When secured, only 150 CFM would be handled.

c. During most of the year's off-hour, a 150 CFM combined supply (or an appropriately larger volume) can satisfactorily hold night temperatures so that minimal warm-up or cool-down period is required. If necessary, such start up loads may be handled by automatic timer prestart of full air volume each morning.

d. The control requirements for such a two-position VAV system are much simpler to develop than for full modulation. In many cases, the 12 to 15 hr/day benefits of this simplified VAV may be preferable to those of the more complex, modulating VAV. This point may be especially true if the low-volume triggering device is employed in some modified fashion during working hours on the basis of the low-volume set point being adequate for unoccupied, daytime loads.

SECTION F - PLUMBING SYSTEMS (EQ-F)

This ECO classification covers plumbing systems including service water, compressed air and waste water systems.

5F.1 SERVICE HOT & COLD WATER SYSTEMS (EQ-F.1)

More opportunity exists in this classification than is generally conceded, especially in those applications which involve substantial hot water use. The following ECOs therefore should be investigated in facilities with large hot water usage.

Water conservation offers most of the basic energy savings in plumbing systems. Any reduction in total flow of water results in pumping energy savings from both flow and pressure drop, either for the municipal system or the private facility system. However, the major energy savings are in the hot water heating and distribution systems.

For groundwater cooling aspects see Section 5H, ECO C-1.3.

ECO W-1 REDUCE PRESSURES

Water flow rates at fixtures and manually controlled equipment are greater at higher water pressures. Operating parts of plumbing equipment, faucets, valves and fittings wear at pressure exceeding 45 psi causing leaks and waste of water and energy.

Based upon the inlet water pressure, the height of a respective building and the friction losses in each piping system, pressure regulators are recommmend where excessive pressures occur. Pressure gauges are recommended on the inlet and outlet of regulating valve assembly. This will permit the building operator to determine if the water pressure is properly regulated and if the regulator is functioning properly.

Hot water consumption for commercial dishwashers and many industrial units is rated by their manufacturers at various operating pressures and regulating valves are recommended. Pressure regulating valves at all equipment should be set at manufacturers' recommended pressure.

ECO W-2 FLOW CONTROL

Design features of faucets, showers, and other industrial and commercial devices will vary with each item. Unrestricted flows from these items are affected by their respective design features. Flow control fittings are designed to avoid excessive flows. They also provide an adequate water supply regardless of pressure. Flow control fittings are available as integral parts of some faucets and shower heads. They are also available as separate adaptable units which could be added to existing shower head arms, individual water supply piping, to sinks, lavatories, and other apparatus. Flow control fittings offer substantial energy and cost savings at minimum installation cost. Spring-loaded shut-off valves and faucets should be considered for faucets, hoses, and other suitable terminal devices. Facilities should be surveyed to determine if such flow control features are included. Appendix 4 "Domestic Hot Water" presents a typical feasibility analysis of the addition of flow control devices.

ECO W-3 REDUCE SUPPLY TEMPERATURES

The energy consumption savings possible at little or no cost, from simply reducing the hot water supply temperatures to plumbing fixtures are not as substantial as many believe, because manual or automatic blending to a given constant final temperature theoretically consumes a proportionally smaller quantity of higher temperature water at the fixture. However, careless manual blending, poor distribution system design, and higher transmission losses from higher water temperatures, still permit substantial cost savings.

The minimum acceptable hot water temperature for each type of utilization apparatus should be determined. In some instances more than one supply temperature level is required. Rather than supplying the highest one to all the fixtures, piping alterations should be made to either generate several temperature levels directly, or to use temperature regulators for multiple supply temperatures off a common generator. Either method insures against the possibility of scalding and allows for improved control. Should one temperature be required, the system temperature can be reduced by maintenance personnel, to take advantage of related savings at no additional cost.

Reduced water temperature will reduce heat losses from generators, tanks and piping, during periods when these losses do not contribute to a desired building heat gain. It will increase the life of all the hardware and piping in the system, by reduction of scaling and corrosion.

Reduced supply temperature does not affect reserve recovery rate or storage if tanks are maintained at existing temperature levels and the main supply is derived by blending with cold water. If reserve is adequate, tank temperature should be dropped to the desired supply temperature, without blending.

ECO W-4 INSULATION

Water heaters, hot water storage tanks and piping insulation should be checked. Faulty insulation should be repaired and sealed. See SITE ENERGY HANDBOOK ECOs S-4, S-5, S-7, S-8 and ECOs CR-1 and CR-2.

ECO W-5 RECIRCULATE HOT WATER

The amount of uncirculated hot water should be determined. Uncirculated pipe lengths in excess of 25 feet will require running (wasting) the water to bring the hot water up to usable temperature. The hot water system design should be reviewed to determine if recirculation can be improved.

Time clock controls should be considered to shut down the hot water circulating pumps when building hot water is not in use.

5F.2 COMPRESSED AIR SYSTEMS (EQ-F.2)

This ECO classification includes the distribution and utilization of compressed air for process or control systems. All ECOs on this subject covered in the SITE ENERGY HANDBOOK apply equally to building energy systems.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO CA-1 LEAKAGE LOSS REDUCTION

ECO CA-2 REDUCTION OF PRESSURE

ECO CA-3 IMPROVEMENT OF AIR QUALITY

5F.3 WASTEWATER SYSTEMS (EQ-F.3)

This ECO classification includes the collection,treatment and disposal of sanitary, process, storm and other wastewater systems. Most ECOs on this subject covered in the SITE ENERGY HANDBOOK apply equally to building energy systems.

RELATED ECOs FROM SITE ENERGY HANDBOOK

ECO WW-1 REDUCTION OF WATER CONSUMPTION

ECO WW-2 SEGREGATION OF WASTEWATER

ECO WW-3 SEPARATION OF STORMWATER

ECO WW-6 MISCELLANEOUS OPPORTUNITIES

5G. PUMPING SYSTEMS (EQ-G)

This ECO classification includes all energy aspects of liquid pumping systems, but its close relationship to many other previously described ECOs has made it necesary to cover important ECO illustrations under various other sections in this chapter as well as in the SITE ENERGY HANDBOOK.

RELATED ECOs IN SITE ENERGY HANDBOOK

ECO P-1 "Pumping and Storage" - Refer to Site ECO W-1

ECO P-2 "Sequenced Parallel or Series Pumping" - Refer to Site ECO W-3

ECO P-3 "Impeller Shaving or Drive Speed Change" - Refer to Site ECO W-5

ECO P-4 "Variable Speed with Existing Motors" - Refer to Site ECO W-6

ECO P-5 "Free Cooling with Ground Water" - Refer to Site ECO W-7 and Reference (46) & (47) of SEH

RELATED ECOs FROM OTHER SECTIONS OF THIS CHAPTER

. Section 5E.1, ECO HF-3.1 "Avoid Continuous Pumping of Fuel Oil"
. Section 5E.5, ECO HCR-4.4 "Install Pumping Equipment that Can Handle Hot Condensate"
. Section 5E.5, ECO HCR-5 "Reduce FW Pumping Requirements"
. Section 5E.6, ECO HHW-5 "Variable Volume Pumping"
. Section 5E.6, ECO HHW-7 "Cycle Hot Water Pumps"
. Section 5E.6, ECO HHW-8 "Change Secondary Pumping to Terminal Boosting"
. Section 5E.7, ECO HCH-1 "Pumping Systems"
. Section 5F.1, ECO W-5 "Recirculate Hot Water"
. Section 5H, ECO C-2 "Pumping Energy Reduction in Coolant Systems"
. Section 5L, ECO O-4 "Keep Air and Liquid Circulating Systems in Optimum Balance"

The above ECOs cover the subject fairly completely. A few additional points may be helpful.

a. Systems characterized by larger flow friction pressure drops, high diversity of loads, and smaller static lift or operating pressure requirements offer better potential for pumping power reduction. Thus, a feed water system for a 400 psig steam boiler with a 25 psi piping P.D. and 30 psi economizer P.D. has only 55 out of 400 psi that can be affected by reduced flow economies. Similarly, a service water pumping system serving a high-rise load with a 250 ft static lift and 70 ft P.D. can only accept reduction in 70 ft portion. Closed systems, on the other hand, are 100% friction P.D., and flow reductions offer potential economies virtually for the entire pump head.

b. Constant volume hot and chilled water systems, especially in larger buildings using motors larger than 15 HP, can be converted to variable flow operation (when compatible with system requirements) for substantial annual Kwh savings. Studies for this type of change require a detailed review of existing control valves and hardware before technical feasibility can be ascertained. However many existing constant flow systems such as those using 3-way valves or wild flow lend themselves to this type of treatment.

c. Pumping systems, particularly those involving long runs to many terminal units, are large energy users and have a substantial potential for energy savings, since they frequently run around the clock. This is particularly true if the diversity of usage varies substantially within the building from day to day; if a sizable portion of the system load is idled during the night; and if constant volume flow design is predominant.

d. Deriving actual BHP requirements from actual pump curves is far more reliable than theoretical calculation. This was illustrated in ECO HCR-4, page 5-47. For practical purposes, a parallel family of curves for various impeller diameters simulates those for different speeds of a given impeller. The relationships of speed, gpm and HP as described in Ref. 46 of the SITE ENERGY HANDBOOK may also be used, for construction of a family of speed and HP curves, but the first procedure is much less tedious.

SECTION H. COOLANT SYSTEMS (EQ-H)

This ECO classification includes all non-refrigerated, liquid, once-through or recirculated systems used for absorption of heat rejected from space, process or equipment.

ECO C-1 ELIMINATE OR REDUCE REFRIGERATED COOLING

Many mechanically cooled systems that operate in a range, any portion of which is above of 40°F for a substantial number of hours, may be an ECO candidate. Several are indicated below.

ECO C-1.1 OBTAIN REFRIGERATION WITH LOW ENERGY INPUT

Examples of this are given in ECO HR-3, Section 5E.3 under "ThermoCycle" and "Strainer Cycle", by utilization of coolant systems.

ECO C-1.2 USE INDIRECT ATMOSPHERIC COOLING FOR HEAT REJECTION FROM REFRIGERATED COOLANT SYSTEMS

Open-circuit cooling towers can furnish a source of coolant which, depending upon system load, is from 2 to 15 F degrees above the ambient wet bulb temperature (wbt). If the existing operation of a chilled water system requires a supply temperature of 60°F (e.g. demineralized water coolant for electronic apparatus), especially if required on a year-round basis, then seasonal conversion to direct process heat rejection in a cooling tower should be considered, in lieu of year-round refrigeration with a conventional condenser water rejection circuit.

With a centrifugal compressor, an alternative to the Thermocycle is a water-to-water heat exchanger that chills the demineralized coolant to the required 60°F when the ambient wbt is below approximately 50°F (in many geographical areas this corresponds to average weather conditions below 59°F dbt.). Similar techniques, as those employed for the EFL ventilating hours described in Chapter 3 for wet bulb load and energy analysis, may be used to evaluate the refrigeration energy savings.

With absorption chillers, the open "Strainer Cycle" could not be used with demineralized water, but the same water-to-water exchanger could be used as described above, to avoid contamination of the demineralized water.

ECO C-1.3 SURFACE OR GROUND WATER COOLANT SYSTEMS

Coolant requirements presently handled by refrigeration can frequently be satisfied year-round with a ready and economically attainable natural source of water. Refer to SITE ENERGY HANDBOOK, ECO W-7.

State Geological authorities furnish detailed data upon inquiry, on the location, prospective quantity and quality of well water in any geographical location. This possiblity should always be investigated.

ECO C-2 PUMPING ENERGY REDUCTION IN COOLANT SYSTEMS

Variable volume pumping for condenser water coolant systems is not usually advantageous, because of the better refrigeration performance at higher volumes. The lower hp/ton ratio, particularly at higher ambient wbt, will normally save far more with the lowest possible coolant temperature than can be saved by cycling tower fans or reducing the coolant flow. When the ambient wbt reduction produces the lowest temperature that the refrigeration equipment will tolerate, then tower fan or flow reduction may not only save auxiliary system energy, but may be necessary for operational reasons.

Most coolant systems, however, are not associated with refrigeration cycles. If so, especially in year round pumping systems with a high diversity of heat rejection load, and/or inadequate equipment load flow regulation, then ECO P techniques in Section 5G should be explored.

Much of the benefit of variable volume pumping can be obtained by simply adding automatic throttling valves at the loads, and, for extensive systems, adding the previously described choke valves on the pump -- without resorting to variable speed pumping for greater savings, at sometimes unjustifiable investment costs.

SECTION I-INDUSTRIAL PROCESS SYSTEMS (EQ-I)

This ECO classification includes all energy nodes which do not fall into the other specific sections of this Chapter. ERDA facilities have a wide variety of very special processes, such as the gaseous diffusion plant at ORNL or the ZGS building at ANL, that are not within the scope of this study.

The ECO Questionnaires approach the subject in a manner that attempts to quickly identify processes which should be examined, with fairly obvious implications of the features which merit close examination. Beyond this, the specific applications can follow any number of concepts, many of which can be treated with the ECO techniques described in the other classifications, and some of which would require a very specialized and specific application of engineering principles.

ECO IG-1 GENERAL (EQ-1.1)

Identify process systems as follows:

- Significant energy use in any form.
- Energy flow characteristics distinctly separate from other classifications in this Chapter.
- High-grade clean energy effluent.
- High-grade dirty energy effluent.
- Large number of full and/or light duty stand-by hours of operation.
- Little or inadequate capacity control with high load diversity and/or erratic load changes.
- Separable energy systems which lend themselves to energy management control.

Study each for ECOs.

ECO IF-1 HIGH FUEL CONSUMERS (EQ-I.2)

After ECO IG-1 identification, check applicability of ECOs in Sections 5E.1, 5E.2, 5J, 5K and 5L.

ECO IS-1 HIGH STEAM OR HOT WATER CONSUMERS

After ECO IG-1 identification, check applicability of ECOs in Sections 5E.2, 5E.4, 5E.5, 5J, 5K and 5L.

Special consideration of:

- Systems without condensate return.
- Vapor escape, non-insulated, inadequate energy containment.
- Low grade energy demands using high grade energy source.

ECO IE-1 HIGH ELECTRICAL CONSUMERS

After ECO EG-1 identification, check applicability of ECOs in Sections 5D, 5J, 5K and 5L.

Special consideration of:

- Voltage regulation
- Demand limiting
- Power factor

SECTION J- MONITORING, CONTROL & SURVEILLANCE SYSTEMS (EQ-J)

This ECO classification includes all specific and general techniques and systems for automatic control, monitoring and surveillance. Some of these ECOs, intimately associated with specific ECOs in other sections of this Chapter, have been presented within those categories. This section presents general ECOs, commonly associated with most of the other classifications, rather than with only one or two.

ECO M-1 NO-LOAD, PART LOAD AND UNOCCUPIED PERIOD CONTROLS

Some of the most substantial, immediate payback modifications for reducing energy waste are based on the simple and obvious principle of turning off energy systems when not needed and tuning them down to deliver no more energy than required at any operating point.

Application of this principle is almost endless. A few important applications follow.

ECO M-1.1 AUTOMATE BY TIME CONTROL (Reference 20)

A very wide variety of automatic time controls is available for almost any desired program of switching, cycling, programming, etc. Some of the more common types follow;

- Astronomical: Automatically compensates for seasonal variations in time of sunrise.
- Delay Timer: Delays On or Off switching action for a set interval after automatic or manual actuation.
- Interval Timer: Set for a desired elapsed time interval -- manually or automatically repeatable.
- Percentage Cycle Repeater: Fixed cycle timer with the length of On-time or Off-time adjustable over a percentage of the cycle. Total cycle time is continuously repeatable and adjustable from a few seconds to 24 hours.
- Externally Initiated Time Control: Starts timing cycle upon initiation by a remote signal.
- Program Time Switch: An accurate time switch with programmed signals that can be set as close together as 5 minutes.

- Repeat-Cycle Time Control: Continually repeats a selected cycle of less than 24 hour duration.

- Seven-Day Time Control: Allows different cycles each day of the week. Each day divided into Morning, Afternoon and Night with up to four On-Off cycles per day. Available with skip-a-day feature to omit the cycle(s) on any day.

- 24 Hour Time Control: Continuously repeats a 24 hour cycle with up to seven On-Off cycles per day. Available with skip-a-day feature.

- Carryover: Many time controls are available with a mechanical spring-wound movement which takes over for at least 10 hours in case of a power failure.

A variety of these time controls can be applied to various energy systems or nodes. Some illustrations are:

a. For building warm-up control, on HVAC systems which are shut down at night, timers should be field set by trial and error to allow for some morning warm-up from lights and occupants, instead of full heating system warm-up to 70-74°F. This is especially applicable when interior areas are involved, since they normally follow the warm-up with a cooling cycle (i.e. requiring supply air temperatures below room temperatures, when normal occupancy ensures). The cycle should also shut outside air dampers (which normally open with the fan start-up) during the warm-up period. During summer cool-down,similarly,the dampers should be shut.

b. Program controls for premature shut-down at the end of the working day to take advantage of storage effect of building.

c. Use timers on all lighting circuits whose size and potential kwh savings justify the cost of the installation. Even a 300 SF office or laboratory with a 600 watt lighting load that is time-clock controlled for 3000 hrs savings per year can save $54/yr. at 3¢/Kwh. Direct switching without a magnetic contactor might permit a rapid payback, if the installed cost were in the neighborhood of $150. Procedures for manual occupant override which still permit supervised shut-off must be developed for individual circumstances. In some instances, manually set interval timers may be acceptable for automatic Off switching after a preset time period.

ECO M-1.2 AUTOMATE BY REMOTE SENSING SIGNAL

Many types of energy operating cycles lend themselves to shut down by remote control devices, such as outside air or return air thermostats. Any devices which can be located and programmed to respond automatically to termination of need for a particular form of energy, should be considered as a substitute for manual cut-off, particularly in buildings having unattended energy systems.

Unoccupied period energy consuming operations associated with controls such as night set-back of temperature, should be cycled On and Off when possible, rather than run continually, for all forms of energy supply.

Winter night set-back and summer set-up temperatures should be handled with an awareness of their effect upon companion systems. ECO COM-1 illustrates how raising summer temperatures with reheat systems can expend more, rather than less energy. Heating season set back in areas that are automatically programmed for mechanical refrigeration or even tempered cold air can create unnecessary cooling or heating loads.

ECO M-1.3 TRACK LOAD WITH AUTOMATIC EQUIPMENT CAPACITY CONTROL

Actual building load reductions should be followed as closely as possible with the reduction of energy system capacities -- not by cancellation of one form of energy with another (e.g. reheat). Also energy systems should be controlled to respond to actual functional needs of the space (e.g. reduce hood exhaust loads when there are no experiments in progress and no hazardous substances being generated).

An important consideration in central capacity control vs zoned capacity control (e.g. resetting discharge air temperature off a cooling coil upward to satisfy only a pre-programmed requirement) is that this tends to override those thermostats which are set much lower than design conditions by the particular occupant. Another example is ambient temperature scheduling of HWS temperatures.

Various ECOs illustrating these fundamental concepts have been presented under various classifications in this HANDBOOK.

ECO M-1.4 MANUAL CONTROL

When equipment shut-down and multi-unit capacity reduction is strictly manual, especially if unattended, and established by regulations and procedural orders, or by off-site Contractor personnel, periodic inspections should be conducted for monitoring of operating status and custodial procedures. It is important in such cases to provide reliable read-out instrumentation to enable the operating staff to appraise the status of system load and capacity for rational, rather than instinctive system manipulation.

If inspections are relatively infrequent and/or personnel in short supply, remote reporting of these status instruments for major equipment components should be considered. See ECO M-3.

ECO M-2 OUTSIDE AIR (OA) REDUCTION

Outside air loads are usually a substantial energy requirement -- sometimes the largest single HVAC component. Numerous references have been made to the reduction of these quantities, including:

- ECO COM-3, "Revised Ventilation Criteria"
- Section 5E.8 Par 2, "Penalty or Benefit"
- ECO HA-1 "Convert CAV Systems to Modified Variable Air Volume"
- ECO HVE-1,"Convert Constant Volume Exhaust To Variable Volume Exhaust".

ECO M-3 INDIVIDUALIZE CONTROLS FOR OPTIMUM ENERGY USE

Individual controls can frequently be justified when the potential for waste is otherwise uncontrollable. Examples are:

a. Overheating in perimeter areas with operable windows from heating devices which are only centrally controlled to satisfy the highest heating load (i.e. north zone) while simultaneously handling sunlit areas with no means of reducing the heat input. Individual thermostat control of the heating unit can eliminate the usual opening of windows.

b. Temperature controls in a zone having simultaneous heating and cooling, where one nullifies the other, instead of sequencing one to a minimum or zero value before starting the other. An example is the change of reheat controls to modified VAV.

ECO M-4 COMPUTERIZED ANALYSIS & CONTROL

The SITE ENERGY HANDBOOK covered this subject and the same observations apply for individual buildings.

A representative list of various computer analysis programs is given below. Some are applicable to computer control, as well as to design. In addition there are many dedicated (specific) programs for specific operating sequences.

ENERGY PROGRAM	ORIGINATOR
	A. Government Programs
CAL-ERDA	Energy Research & Develop. Adm.
NICAP	National Aeronautics & Space Adm.
NBS LOAD PROGRAM	National Bureau of Standards
POST OFFICE	U.S. Postal Service
	B. Commercial Programs
ECUBE	American Gas Association
HCC-111	APEC
Energy Analysis	Caudill Rowlett Scott
AXCESS	Electric Energy Association
Glass Comparison	Libbey-Owens-Ford
Energy Program	MEDSI
Energy Analysis	Meriwether & Associates
Building Cost Analysis	PPG Industries
TRACE	TRANE Company
Energy Program	Westinghouse Corp.
HACE	WTA Computer Services, Inc.
	C. Research Programs/Negotiable
CADS	UCLA
SIMSHAC	Colorado State University
FINAL	Dalton, Dalton, Little & Newport
HVAC Load	Giffels Associates, Inc.
Energy Program	Honeywell, Inc.
NBSLD(Honeywell)	Honeywell, Inc.
Energy Program	University of Michigan
B.E.A.P.	Pennsylvania State University
DEROB	University of Texas
TRANSYS	University of Wisconsin
	D. In-House Program/Proprietary
Energy Program	General Electric Company
Residential & Small Commercial	Honeywell, Inc.
Energy Program	IBM

SECTION K - WASTE ENERGY RECOVERY AND REDUCTION (EQ-K)

This ECO classification includes all aspects of energy recovery for productive utilization, from waste solids, gases or liquids; also the reduction of energy waste from leakage and from incomplete use of energy potential. Many opportunities exist for utilization of an energy flow stream in two or more successive steps of degradation, from high-grade to low grade thermal levels and through conversion to other forms. Such repeated use is an important key to recovery.

5K.1 HVAC RECOVERING SYSTEMS (EQ-K.1)

This classification includes recovery techniques that apply to the low grade energy common to HVAC systems - not to the higher grade levels such as flue gas or other emissions from process systems. Recovery may be by direct recycling or reuse, purification and reuse, heat exchange or conversion process.

ECO WH-1 DIRECT RECYCLING OF SPENT AIR (EQ-K.1b)

Uncontaminated air which has been conditioned, served its purpose and exhausted can often be easily transferred to an adjacent area for heating, cooling or ventilation make-up. Examples are:

a. Conditioned ventilation air to a restaurant (or other high make-up requirement area) routed to kitchen (or other exhaust-intensive area).

b. Clean, warm process exhaust, routed to nearby heated area during heating season, exhausted during cooling season, and modulated with return air or outside air for temperature control.

ECO WH-2 PURIFY EXHAUST AIR FOR RECYCLING (EQ-K.1a)

Filtration, spray wash or activated carbon are often justifiable for exhaust air treatment to permit its direct reuse.

Candidates for such treatment with activated carbon are central exhaust systems from toilet areas, dining rooms, lounges, etc. To recirculate the air, ducting must be installed to connect from the discharge side of the exhaust system into the return air of the HVAC system. This ductwork contains the activated carbon filters. Recirculate that portion of the quantity of total exhaust air for the building which exceeds 90% of minimum outdoor air requirements.

This technique is easier to justify from a cost standpoint than heat wheels or heat pipes, covered in the next ECO, provided that the exhaust volume returned can be bled from the exhaust without disruption of the building balance.

ECO WH-3 RECOVER HEAT FROM BUILDING EXHAUST AIR SYSTEM(EQ K.1.b)

With outside air supplied to a building at temperatures ranging between 0°F and 95°F and normal exhaust air temperatures averaging 75°F, heat can be effectively transferred between the supply air and the exhaust air, depending upon which stream is warmer.

Summer recovery to precool outside air (OA) supply from cool exhaust presupposes that the exhaust stream is from conditioned spaces and has not been heated to temperatures approaching or above that of the OA (e.g. while passing through a process heating device before being exhausted).

There is a variety of these recovery methods each having its application to a particular type of building system. Limitations as to the heat recovery method used are also imposed by the physical proximity of supply and exhaust equipment, possibility of contamination of the supply air source and climatic conditions. When a heat recovery opportunity exists the following basic heat recovery methods should be considered for economic evaluation:

a. Rotary air wheel

b. Heat pipe

c. Circulating liquid, or run-around system.

ECO WH-3.1 ROTARY AIR WHEELS & PLATE HEAT EXCHANGERS

Some rotary wheels and all plate exchangers transfer sensible heat only while other wheels transfer both sensible and latent heat, summer and winter. The latter are also referred to as enthalpy wheels. Factors that limit the application of the heat wheels and plate exchangers are the relative location of the supply and exhaust air streams, effect on fan static pressure,

space requirements, contamination criteria for the air stream in question and leakage between streams. Heat recovery wheels are available in single units ranging from 300 to 50,000 cfm. For larger capacities multiple units may be installed. Efficiencies at equal flow of both streams average approximately 70%. Air flow should be designed for counterflow for maximum efficiency and to keep the wheel free of dirt.

Fig. WH3-1 shows a schematic diagram of an enthalpy wheel. It employs a dessicant such as lithium chloride impregnated in the heat exchange material which absorbs moisture. The formulae for the relationships which govern are as follows (with s, o and e indices representing supply, outside and exhaust, respectively):

a. For Sensible Heat Transfer, the supply air temperature T_s at the wheel outlet for equal supply and exhaust cfm is given by:

$$T_s = T_o + (T_e - T_o)\ Eff_{sens}$$

For unequal supply and exhaust volume it is

$$T_s = T_o + \frac{CFM_e}{CFM_s} (T_e - T_o)\ Eff_{sens}$$

b. For Latent Heat Transfer, the humidity ratio, W in lbs moisture/lb dry air is given by

$$W_s = W_o + (W_e - W_o)\ Eff_{lat}$$

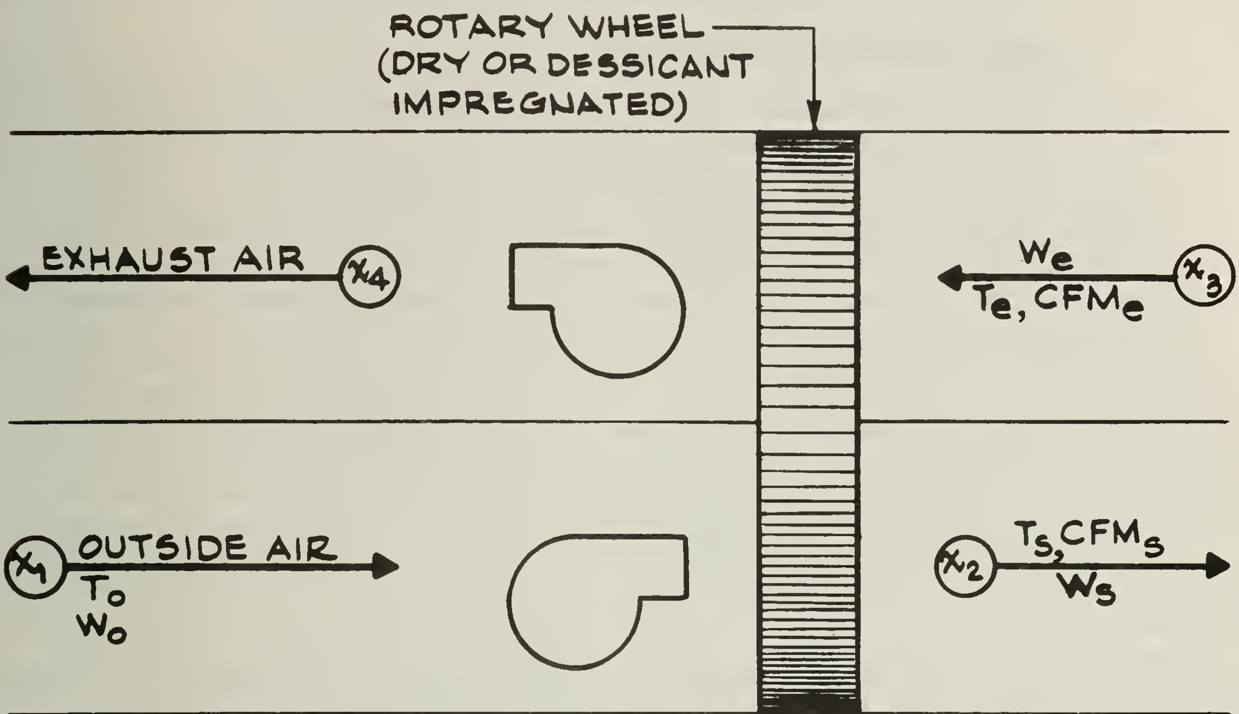
The efficiency for sensible and latent heat transfer will vary for a given wheel operating under different conditions. This must be taken into account when designing a heat wheel system.

Similar relationships govern sensible heat wheels.

ECO WH-3.2 HEAT PIPE

The heat pipe is a non-regenerative conducting device, air-to-air recovery unity that has no moving parts. It consists of an array of finned tubes which are sealed at both ends and arranged similar to a dehumidifying or cooling coil. Each tube is filled with a wick and a charge of wicking fluid. Common working fluids used for comfort air conditioning systems include refrigerant, water and methanol. For high temperature application, liquid metals are preferred as the working fluid. The heat pipe is a reversible thermal device. When a section of the tube bundle is exposed to a temperature gradient with respect to another section, the cycle will commence and attempt to eliminate the gradient. Heat, applied to one end, evaporates the working fluid. The vapor flows to the cold end of the tube where it is condensed and returned by the wick to the hot end for re-evaporation, completing the cycle. This device transfers only sensible heat. There is no contamination since the heat pipes are installed with opposite ends projecting into each air stream and a sealed partition between hot and cold ends.

FIG. WH 3-1
SCHEMATIC OF HEAT RECOVERY WHEEL



W = HUMIDITY RATIO, lbs moisture / lb dry air

T_S = SUPPLY AIR TEMPERATURE

T_O = OUTSIDE AIR TEMPERATURE

T_e = EXHAUST AIR TEMPERATURE

CFM_S = SUPPLY AIR QUANTITY

CFM_e = EXHAUST AIR QUANTITY

Eff_{SENS} = SENSIBLE HEAT RECOVERY EFFICIENCY

$Eff_{LAT.}$ = LATENT HEAT RECOVERY EFFICIENCY

EFFICIENCY OF WHEEL WHEN $CFM_S = CFM_e$
AND X = TEMPERATURE,
HUMIDITY RATIO OR ENTHALPY.

$$Eff = \frac{X_1 - X_2}{X_1 - X_3}$$

Control of the rate of recovery may be accomplished by conventional face and bypass dampers or tilting variation.

ECO WH-3.3 RUN-AROUND SYSTEM-CLOSED TYPE

A closed loop run-around system is a recirculated hydronic system. It mainly transfers sensible heat, although latent transfer can occur under special operating conditions. The heat passes from one air stream to a fluid medium (e.g. glycol or water) and back from the fluid to another air stream. Standard extended surface finned tube, water coils are used with one coil located in the exhaust air stream and the other in the supply air stream. A pump circulates the water or solution between the coils, transferring heat from the exhaust recovery coil to the supply air coil. For maximum efficiency the direction of flow of solution in relation to the air is generally counterflow. The air to be preconditioned by the supply air coil will reflect an approach to the temperature of the solution from the exhaust air coil, thereby preheating in the winter and precooling in the summer. The finned coils may be sprayed to acquire better recovery for summer operations. During the winter it is possible for the solution temperature to be lower than the exhaust air stream dew point temperature, causing condensation on the exhaust air coil. This can result in additional air side pressure drop and a need for drainage. Although this condition would be the exception rather than the rule, provisions should be made to take care of it. The use of a 3-way valve controlled by a dew point controller located in the leaving exhaust air stream can be used, at the expense of recovery efficiency, or drainage can be provided without loss of recovery potential. The pump may be located at any convenient point in the piping loop, and an expansion tank must be installed on the suction side to allow for expansion in the water and also to insure a net positive suction head.

The closed loop run-around system can be used where outside air intakes and exhaust terminating locations are wide apart, and it also eliminates the cross contamination problem.

ECO WH-3.4 RUN-AROUND SYSTEM-OPEN TYPE

The system is similar to the closed loop system. An extended packed surface, such as a cooling tower fill, is substituted for the cooling coils and a liquid, absorbent such as lithium chloride/water, is substituted for the water/anti-freeze circulating liquid. Another difference is that the absorbent liquid is sprayed counterflow to the air streams through the extended packed surface. This requires two solution pumps to complete the run-around circuit.

This system provides total heat or enthalpy transfer as the solution absorbs or desorbs heat and water vapor from the exhaust air stream. By circulation and contact with the solution, the supply air stream is preconditioned to approach the solution's temperature and vapor pressure difference. The system is also reversible because its action, similar to that of the hygroscopic rotary exchanger, will precool and dehumidify in the summer and will preheat and humidify in the winter. During the winter operation, it is imperative that the absorbent solution be kept liquid when handling dry exhaust air. If the water concentration of the solution is reduced to about 50% when drying at approximately 11% RH or less, the lithium chloride solution will solidify and clog pumps, spray nozzles and piping.

Equipment selection generally provides recovery efficiency at 55% to 70% enthalpy. The system can also serve air streams which are far apart but, because of its open spray nature, cross contamination is possible. The solution spray acts as an air washer or scrubber, with evaporative cooling benefits.

ECO WH-4 RECOVER INTERNAL HEAT WITH HEAT PUMP (EQ K.1.c)

The most advantageous heat pump applications are those which are used when the rejected heat can be 100% utilized, while the refrigeration energy is in simultaneous demand--with no more refrigeration generated than is demanded. It is most desirable for the cooling load which is satisfied by the refrigeration to be one that cannot be served from an alternate, less expensive cooling source. Thus, an internal source heat pump which applies heat extracted from a building interior to a perimeter heating load could use outside air in a true "free cooling" cycle for the interior (rather than refrigeration) with a prime source fuel for the perimeter heating. In such a comparison, the heat pump is only an economic advantage if its electrical cost per 10^6 Btu of rejection output is lower than that of source fuel. This heat pump's energy advantage over an efficient fired system is approximated as follows for an 11,600 Btu/Kwh power plant conversion, and a factor of 1 Kwh of refrigeration plus auxiliaries per 15,410 Btuh of rejection:

Heat pump source input per 15,410 Btu output = 11,600 Btu
Fired boiler input per 15,410 Btu output @ 80%= 19,250 Btu
Energy reduction with heat pump = 40%

However, if the refrigeration energy were actually required for process, while the rejected heat was also utilized, the cost of this rejected heat is virtually zero. The energy advantage improves as follows, because of the additional output of 12,000 Btu of cooling:

	Input Energy-Btu	
	Heat Pump	Conventional
Refrigeration output of 12,000 Btu	11,600	11,600
Heating output of 15,410 Btu	0	19,250
Total heat pump output = 27,410 Btu	11,600	30,850

Energy reduction with heat pump = 62.4%

A third option would be to obtain the cooling with a Thermocycle (ECO HR-3), in which case a fired boiler would again be required, tending to reduce the justification for the Thermocycle, compared with the heat pump.

An important energy caution for wheel, plate or run-around recovery systems applies to their use with heat pump systems. As long as the heat being recovered from the condenser of the heat pump is adequate to carry the heating load at any particular system load point, there is no purpose in reclaiming additional heat from exhaust streams.

5K.2 COMBUSTION AIR AND FLUE GAS SYSTEMS (EQ-K.2)

This ECO classification covers heat recovery techniques that apply to higher grade energy available from comfort or process combustion equipment.

Flue gases emitted from boilers and incinerators and exhaust gases discharged from internal combustion engines, process equipment and gas turbines, are valuable energy sources. The gases from these sources range in temperature to 2000° F and offer excellent heat transfer possibilities. The recovery of this wasted heat is affected by waste heat boilers, air-to-air and air-to-water heat exchangers. There are limitations in recovering heat from hot gases. First it is important (when sulphur dioxide and other injurious vapors are present) to stay above their dew point to prevent condensation. For example the resulting condensate from fuel oil combustion is highly corrosive sulphurous or sulphuric acid. Often, it is necessary to use corrosion-resistant materials in the heat exchanger. Stack gas preheating of fuels is generally prohibited by safety codes. Generally the most cost effective use of flue gases burned with normal excess air is for liquid heating (e.g. feedwater preheat).

ECO WCF-1 PREHEAT COMBUSTION AIR AND/OR FEEDWATER WITH FLUE GAS

The justification for economizers and air preheaters increases with the rise in boiler pressure/temperature. As the latter rises so does the flue gas temperature. Any stack temperature above the temperature at which condensation corrosion might occur, represents a serious energy loss.

The cost effectiveness of an economizer is substantially greater than for an air preheater, with minimal chance of condensation corrosion when the economizer follows a deaerator.

The heat recovered from flue gases may be determined as:

$$Q_r = M_e \times C_p \times T$$

Where:

Q_r = Heat recovered, Btuh
M_e = Flue gas mass flow, lbs/hr
C_p = Specific heat, Btu/lb - ^oF (see Fig. WCF 1-1)
T = Temperature drop of flue gas, F degrees

The appropriate fuel savings derived when combustion air is preheated is shown in Fig. WCF 1-2.

FIG. WCF 1-1

SPECIFIC HEAT OF FLUE GAS

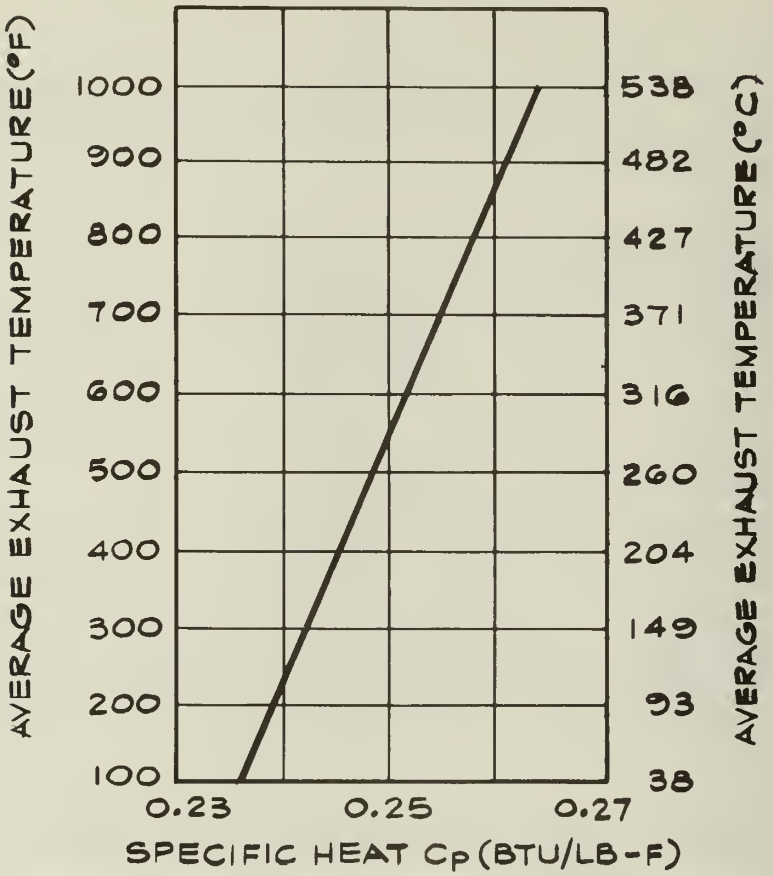
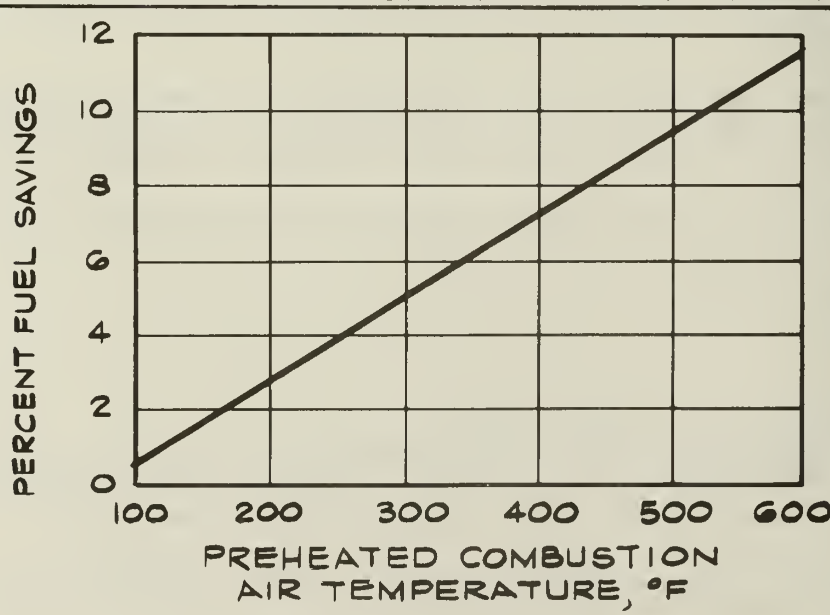


FIG. WCF 1-2

PERCENT OF FUEL SAVINGS WITH AIR PREHEAT *



APPROXIMATE IMPROVEMENT IN EFFICIENCY WHEN HEATED COMBUSTION AIR IS USED IN BOILER UNITS.

* REFERENCE 21

5K.3 HOT LIQUID EFFLUENT OR RECIRCULATING SYSTEMS (EQ-K.3)

This ECO classification includes recovery techniques associated with hot liquids from process systems.

ECO WL-1 RECOVER HEAT FROM PROCESS COOLANT SYSTEMS

In the SITE ENERGY HANDBOOK, Sect. 5E.1.3, ECO S-1 is the description of modifications suggested to the planned recovery of heat from the gaseous diffusion process at ORNL. (Heat is presently rejected at 140-150° F level to a cooling tower). These refinements to the proposed plan illustrate how the manner in which the low grade heat is transported and used can have a substantial impact on the feasibility of recovery.

The low temperature level and small ΔT involved in such recovery systems require the most imaginative use of the low grade heat, to ensure economic feasibility.

ECO WL-2 RECOVER HEAT FROM WASTEWATER

If hot process effluent is isolated and collected before discharge into a common wastewater system with cold effluent, then direct heat exchangers or heat pump systems may be considered. The temperature level must be compatible with the system used. The demand and the heat exchangers as well as piping must also be adequately compatible with the waste medium to insure reasonable maintenance costs and life expectancy.

Instances arise when the waste stream is a reasonably clean coolant that has simply been heated in closed circuit processes. Its re-use may be a matter of justifiable storage and pumping to some subsequent process, which needs hot water in a once-through type cycle such as washing or flushing.

5K.4-HOT AIR, VAPOR OR GAS EXHAUST (EQ-K.4)

This ECO classification covers heat recovery techniques that apply to hot air vapor or gas exhaust streams from process systems.

ECO WHG-1 USE HOT AIR EXHAUST AS PREHEATED COMBUSTION AIR

Air from hot air drying equipment or from the hottest ceiling level location in a boiler room can be directed to the boiler combustion air intake instead of being exhausted. The savings are indicated in ECO WCF-1.

Contaminents in the hot air which might be an ecological problem, but not a furnace or boiler corrosion problem can be burned in this manner, with the heat generator serving as a fume incinerator.

ECO WHG-2 RECOVER ENERGY FROM PROCESS GASES AND VAPORS

Recycle gases and vapors when possible, or use energy exchangers for reducing prime energy service consumption.

5K.5-ENERGY LEAKAGE (EQ-K.5)

This ECO classification covers techniques of heat loss reduction from comfort and process systems, arising from conduction, transmission, radiation and physical leakage of energy to or from equipment or streams which are higher or lower in temperature than their surroundings.

This subject has been covered in various ECOs in the SITE ENERGY HANDBOOK and elsewhere in this Chapter, as follows:

ECO WLK-1 LEAKAGE & ENERGY LOSS MANAGEMENT FROM SITE ENERGY HANDBOOK

- See ECOs S-4, S-5, S-7, S-8 for steam & hot liquids
- See ECOs CA-1 & CA-2 for compressed air
- See ECO CR-1 & CR-2 for condensate return

FROM THIS HANDBOOK

- See ECO HCR-4 Flash Losses
- See ECO HH-4 Blow Down Losses
- See ECO HH-5 Stack Losses

5K.6-SOLID WASTE RECOVERY

This ECO classification includes the recovery from incinerator or pyrolysis of solid waste.

ECO WSW-1 RECOVER HEAT FROM PYROLYSIS OF SOLID WASTE

Refer to SITE ENERGY HANDBOOK. ECOs SW-4 & SW-5

SECTION L- OPERATION & MAINTENANCE (EQ-L)

This ECO classification includes all aspects of operation, maintenance and repair which affect energy consumption. Probably the largest single area of conservation potential which can be effected with little or no investment cost lies in the O & M aspects of energy systems.

Many such specific aspects have been covered in the particular energy system classification in other ECO sections.

Costs of replacement materials and parts have been increasing faster than those of labor, and deliveries have been stretching out, adding to increased risks and losses from down-time. It is becoming increasingly important to optimize O & M for longer, more reliable operation, with the emphasis on timely repair and preservation of equipment rather than its replacement.

Furthermore it is now more widely recognized that deficient O & M can not only cause premature failure of equipment but also causes serious increases in energy consumption which, at current costs, mandates the most efficient O & M possible.

ECO O-1 OPTIMIZE O & M RECORDS AND ANALYSIS (EQ-L.1)

Prepare comprehensive O & M manuals and as-built drawings and records of systems, instrumentation and controls.

a. The accumulated operating experience for each building should be coordinated with available drawings, specifications and vendor manuals for a composite Instruction Manual of each system's design intent, its relationship to other systems, control functions and sequences of equipment operation.

b. Optimization of existing energy systems can be best effected after such records are accumulated, permitting an overall view of how any one change effects the overall system. The record itself may be utilized as an educational tool for increased awareness of all operating personnel as to the impact of specific procedures and control functions upon energy conservation.

Develop a full energy audit from the survey and appraisal concepts established in this HANDBOOK.

Organize an energy-oriented O & M program:

a. Develop logging procedures which lead to on-going performance monitoring and appraisal of all major energy nodes and systems.

b. Establish training programs for operating personnel with the goal of familiarizing them with the design intent of their facility's systems. This leads to a better understanding of energy optimization in any complex building. Maintain a free flow of information conducive to suggestions for improvement.

c. Supplement preventive maintenance programs with predictive maintenance on units which are readily adaptable to it. Predictive maintenance is based upon logging key measurements of equipment or systems from historic knowledge of how they should be operating and performing at existing conditions.

   When maintenance is indicated it can then be scheduled to avoid untimely breakdowns and a minimum of unnecessary maintenance can be effected by disassembly only when required. The common heat exchanger, monitored with accurate instrumentation for temperatures and flow, is a good example.

ECO O-2 PROGRAM CUSTODIAL OPERATIONS FOR ENERGY CONSERVATION (EQ-L.2)

To the extent possible, custodial operations should be conducted during regular working hours. When this is not feasible, each section with an isolatable HVAC and lighting circuit should be cleaned at a time, with all personnel concentrating on one section and/or one building at a time -- not spread through the building and/or site and running all services during the entire cleaning period for the building and/or site.

All personnel should be made familiar with the location of lighting panel switches and power equipment whose shut down does not require skilled maintenance. The cost of supervising this function closely can be readily justified by electrical and associated energy system savings.

ECO O-3 KEEP HEAT EXCHANGERS CLEAN (EQ-L.3)

For essential, critical or continuously operating exchangers without stand-by, consider the following options:

a. Preventive or predictive maintenance program based upon required instrumentation for adequately accurate diagnosis of on-line performance.

b. On-line cleaning systems for large units. References 22 & 23.

c. Re-evaluation of chemical treatment practices and up-grading if indicated.

Evaluation of losses from power and energy consumption increase can be approximated by construction of data from actual operating conditions as to fouling thickness vs loss in performance. Performance can be measured in terms of loss in cooling or heating effect as well as increase in power or input energy requirement. For example the penalty in cooling effect on a centrifugal chiller with a dirty chiller and condenser can be 25% with an accompanying power increase of 50%.

ECO O-4 KEEP AIR & LIQUID CIRCULATING SYSTEMS IN OPTIMUM BALANCE (EQ-L.4)

Several examples have been given in various ECOs in the SITE ENERGY HANDBOOK as well as in this HANDBOOK, which demonstrate the techniques and evaluation procedures for this ECO.

The magnitude of energy required for liquid and air circulation systems is often more than that for the production of the energy being transferred -- or at least substantial by comparison. Trimming of these systems by skilled personnel with a full understanding of the system's operation, the use of field instruments and the means of correction is paramount to effective application of these ECOs.

The key to conservation in circulating systems is to avoid the parasitic consumption of energy for balancing with unnecessary throttling of manual and automatic balancing valves and dampers.

a. Trim pump impellers or reduce speed of pumps or fans at full load to provide no more than the pressure required at the farthest terminal, with all valves and restrictions in the governing circuit wide open.

b. Check the requirements in a properly balanced and trimmed circulating system at various part load conditions, to determine potential for control method which respond to reduced circulation.

It is frequently more rewarding to trim systems for optimum performance at a part load condition that has a much higher annual block of operating hours than the full load condition. Not all equipment operates at best efficiency at 100% full load. Manufacturers of all major equipment should be requested to furnish performance curves through the range of loads experienced in the facility, or they should be developed from field data and testing when possible.

c. Follow conventional, recommended maintenance procedures on belt tension, filters, etc., to maintain the integrity of optimum balance by avoiding degradation of the system components.

APPENDIX 1

ECO RELATED QUESTIONS (EQ)

A. GENERAL

A.1. Energy-Related Record Keeping

a. Is all entering energy logging for a common time interval?
b. If not logged that way at present, is it under the control of plant personnel?
c. If product output is involved, is that logged for same period or not?
d. Are fuel logs kept on as-used or as delivered basis?
e. List all energy related records which are kept with type of measurement and interval basis.
f. Are any public utility meters inaccessible to plant personnel?

A.2. History of Facility's Energy Conservation Measures

a. List all installations of retrofit equipment for heat recovery, resource reclamation and Energy Conservation completed or currently contemplated.
b. Indicate investments involved and results obtained.
c. List all "no-cost" conservation programs instituted since 1970 and their results for:

   1) Lighting
   2) Power
   3) HVAC
   4) Process

d. List ECOs being applied or contemplated.

A.3. Are any major equipment additions or replacements programmed, contemplated or felt necessary? Have they any ECO potential?

A.4. Give details of major maintenance or operating problems, especially recurring ones in connection with any energy systems.

ECO RELATED QUESTIONS (EQ)

B. BUILDING SKIN

B.1. Construction

a. Quality of walls and general construction. Age and condition of building? Insulated? Leaky?
b. %glass in walls & roof; details if other than plain, single glazing. Percent operable glass. Type window. Leaky? Recently caulked?
c. Roof: Insulated? Flat or pitched? Bonded?

B.2. Entrance Protection

Any special loading entrance protection? (i.e. air curtain, truck vestibule, dock sealers). Door use frequency.

B.3. High Bay Areas

a. Is height still required (i.e. function or process changed).
b. Can volume and skin loads be reduced with hung ceiling?

ECO RELATED QUESTIONS (EQ)

C. COMFORT, USE AND OCCUPANCY

C.1. Comfort

a. Area of building with special requirements such as:

1) Close temperature/humidity control? .... SF, ...°FDB/ ....%RH
2) Summer high limit ....%, ...RH; low limit ....%, ...RH
3) Mandatory year-round cooling ...SF
4) Mandatory year-round ventilation and/or exhaust ....SF, Minimum: ....CFM/SF; .... air change rate.

b. Normal conditions maintained other spaces ..... °FDB/ .....%RH.

C.2. Present Use Profiles

a. Time of Day -

	NORMAL SPACES			
	COOLING		HEATING	
	START	STOP	START	SET BACK
WEEKDAY				
SATURDAY				
SUNDAY & HOLIDAY				

	SPECIAL SPACES			
	COOLING		HEATING	
	START	STOP	START	SET BACK
WEEKDAY				
SATURDAY				
SUNDAY & HOLIDAY				

ECO RELATED QUESTIONS (EQ)

b. Cleaning Procedures: Size Crew; hrs/day allowed; % of lights, htg and cooling equipment operated.
c. Special energy systems usage after normal occupancy.
d. Occupancy Profile

C.3. Estimated Comfort Quality Rating

C.4. Reappraisal of Criteria

a. Are all spaces allocated for optimum use and comfort?
b. Can occupancy, function and comfort conditions be reprogrammed to eliminate or reduce energy requirements by grouping similar functions, partitioning diverse areas, etc.

ECO RELATED QUESTIONS (EQ)

D. ELECTRICAL SYSTEMS

D.1. Service

a. Transformer loading.
b. System load factor: high and low month, and annual average.
c. Power factor.

D.2. Lighting System

a. Current switching procedures and automatic controls.

   1) normal use areas
   2) special use areas
   3) low usage areas (i.e. storage, corridors). Systematic off-hour monitoring?

b. Do lighting circuits in ECO-potential areas lend themselves to automation? On-off? Dimming?
c. Is there potential for reducing lighting loads in naturally lit areas?
d. Are magnetic contactors installed?
e. List production and mechanical areas with lighting above OSHA level intensities?
f. Lamping types and their adaptability to retrofit ECOs
g. See EQ-A.2.c. (recent lighting ECO history).

D.3. Power System

a. Are motors being run at near full load? Can they be changed?

D.4. Load Management

a. Are there any block loads which lend themselves to shedding or load deferral?

ECO RELATED QUESTIONS (EQ)

E. HVAC SYSTEMS (Comfort & Process)

E.1. HVAC Fuel & Combustion Systems

a. Fuel Oil Handling & Preparation (Between Storage & Burner).

1) Continuous transfer pumping or day tank(s)?
2) Pressure relief valve setting and relation to end-line pressure required? Return to where? Is preheated oil returned to main storage tank?
3) Tank and /or suction line heating means.
4) Special treatment or additives.
5) Fixed or variation in set point of preheat temperature? Type of temperature control and heating media.

b. Is Fuel Oil Consumption totalized? Type; logging interval;Are there locations where meters could be installed to measure total for plant or each unit? Is there simultaneous measurement of heat or power generation product output? Describe.

c. Current Monitoring, Testing, Measurement.

1) Fuel temp., pressure, viscosity, flow rate.
2) Combustion air temp., flow rate, preheating.
3) Exhaust gas analysis; hi-low temp. range at full and low load. Common exhaust stack? Dampering?

d. Describe combustion controls and frequency of trim. Are they trimmed by facility personnel or an outside contractor?

ECO RELATED QUESTIONS (EQ)

E.2. HEAT GENERATING PLANTS

a. Efficiency Monitoring? Frequency; directly by product and fuel measurement or indirectly by fuel gas analysis and temperature? ΔT between stack and generator output temp.? On-line or manual? Was firing ever changed (e.g. gas to fuel oil)?

b. Generator Lighting & Sequencing

1) What sequencing practices are used for meeting varying plant load conditions with standby in case of failure.
2) Are they shutdown during nights, weekends and no-load periods?

c. Auxiliary Data

1) Economizer
2) F.W. heater
3) Deaerator
4) Air preheat
5) Evaluation of heat balance (i.e. steam turbine to motor drive ratio).

d. Blow-Down

1) Automated from either raw water make-up or boiler steam production? Valve position indicator and downstream fixed orifice for low loads? Modulated? Total dissolved Solids (TDS) or flow sensing?
2) If manual; intermittent or continuous or both? Describe sequence, interval.
3) Open sight view of drainage?
4) Heat recovery for air or water preheat? Flashed or cooled to sewage without recovery?
5) Is effluent monitored?

e. Tube Cleaning and Soot Blowing

1) Automatic or manual? Fire tube or water tube?
2) Procedure and frequency.

ECO RELATED QUESTIONS (EQ)

3) Chemical, mechanical or compressed air?

f. <u>Boiler and Make Up Water Treatment?</u>
Describe.

g. <u>Breeching damper</u> for draft and/or shut-down control?

ECO RELATED QUESTIONS (EQ)

E.3. REFRIGERATION PLANTS

a. Chilled Water (Ch.W) Supply Temperature Control

1) Fixed or variable? Describe controls.
2) Does Ch.W. system lend itself to scheduling or reset? Is it direct from room condition, ambient condition or air system supply condition?

b. Condenser Water (C.W.) Supply Temperature Control

1) Fixed or variable? Describe controls
2) Lowest acceptable C.W. temperature required to avoid surge or chrystallization.
3) Purge monitoring, procedure & frequency.

c. Appraise Tube Fouling in Chiller & Condenser

1) Frequency of cleaning.
2) Evaluation of fouling.
3) Is transfer rate monitored by ΔT?
4) Is chemical treatment used?

d. Variable Flow Control- present chiller tube velocity.

e. Heat Pump Potential

1) Installed capacity of all refrigeration units operated during winter cycle.
2) List service, process or HVAC low level hot water requirements during refrigeration operating periods (100 to 115° F). What is the proximity of such loads to the refrigeration units?

f. Is current limiting control installed? Is it used?

g. Describe start-stop procedures, sensing and means for refrig. capacity control, use multiple-unit sequencing practices.

h. Is there a potential for Thermocycle or Strainer

ECO RELATED QUESTIONS (EQ)

Cycle? What is number of hours operation below 55° F ambient.

i. Lube-oil maintenance procedure.

j. Cooling Tower - winterized? How? Describe capacity control method.

k. Is there any means for input and/or output energy measurement?

ECO RELATED QUESTIONS (EQ)

E.4. STEAM DISTRIBUTION SYSTEM

a. Transmission, Leakage & Energy Loss Management

1) Adequacy and condition of insulation, piping and valving.
2) Is there a possibility of a leakage test run during minimum steam demand, without blowdown? Can essential loads during such test be metered?
3) How many measuring and calculating techniques can be applied for cross-checking steam losses? How many of following items are metered and appraise the accuracy of the metering system.

   (a) Steam generated (S_{gen})
   (b) Feedwater (FW)
   (c) Make-up (MU)
   (d) Steam Consumed in Plant (S_{chp})
   (e) Steam to D.C. Deaerator (S_{da})
   (f) Steam to burners (Satom)
   (g) Condensate return (CR)

4) Is there a steam trap inspection program? Is there any untrapped apparatus?
5) Are there extensive flash losses from flash and condensate return tanks? Utilization equipment? Condensate dumping?
6) Itemize and describe any direct steam injection equipment.
7) Are there adequate personnel and accessibility for an up-to-date leakage repair program?

b. Pressure Reduction and/or Shut-Down of Redundant Mains

1) Is there any indication of substantial reserve in any steam mains? Were loads substantially reduced since system start-up?
2) Can utilization equipment tolerate lower pressure in mains, either on seasonal or year-round basis?
3) Is the percentage of High Pressure Steam users below 5% of total? Are they essential loads?
4) Is distribution system pressure profile available at full load?

ECO RELATED QUESTIONS (EQ)

c. <u>Potential for Timed Shutdown of Sections or Entire Building</u>

1) Location of critical or essential steam service loads, if any.
2) Are there sub-mains serving users which can tolerate substantial periods or intermittent short periods of shut-down?
3) Do these sub-mains have auto control valves or PRVs? Are they self-contained or pilot operated?
4) If essential warm-weather steam loads are served from segregated mains, or are a very small percentage of the total load on a main, can a practical alternative heat source be considered?
5) Is there any systematic seasonal manual shutdown program?

d. <u>Low Pressure Steam (LPS)</u>

1) Are there any Back Pressure or Extraction Turbines? Is optimum use made of the steam? Is there an excess LPS by-product at any time?
2) Are there any other potential users of LPS or low level heat? Is any carrier piping or media available to transport it to the point(s) of use? How far away are points of use? Are any LPS users currently being fed exclusively from a PRV?
3) Are there any available low level heat carriers or demands close to atmospheric, HP or MP flash tank vents? (i.e. LPS mains, cold make-up or service water preheat).

ECO RELATED QUESTIONS (EQ)

E.5. CONDENSATE RETURN AND FEEDWATER SYSTEM

a. Condensate Return Tank(s) & Make-Up (MU)

1) Does annual high, low or average return temperature from steam system exceed 200 F? Is tank vented to atmosphere? Vent Condenser?
2) Is condensate cooling used? Is there direct injection into tank or through heat exchanger? Is flashing eliminated? Is flow volume of make-up adequate to prevent flash losses at all times?
3) Is there any unvented pressurized condensate return?
4) Can temperature of make-up system return and blended supply from tank be measured for a crosscheck of the metered flow rates?
5) Is tank insulated? Exposed to weather?
6) Is there adequate chemical treatment of make-up water?
7) For low % MU systems (below 15%), is pumpless return worth consideration?

b. Feedwater System

1) Dearator

(a) Mfr
(b) Size
(c) DC?
(d) Vented?
(e) Steam P/T
(f) FW temp. entering and leaving
(g) Is there vent condensing? Is it effective?
(h) Dissolved oxygen.

2) FW Pump(s)

(a) Continuous or intermittent?
(b) Steam drive?
(c) Rated gpm and discharge pressure
(d) What is entering pressure at tail-

ECO RELATED QUESTIONS (EQ)

end FW control valve at system full load, and low load

(e) Type and size each FW valve and rated flow for each boiler.

(f) Common pumping, or unitary for each boiler?

(g) Standby?

(h) Capability for variable speed pumping, or pressure reduction.

3) Describe meters, gages and thermometers in current use.

4) Is there a monitoring program on feedwater quality control?

ECO RELATED QUESTIONS (EQ)

E.6. <u>HOT WATER DISTRIBUTION SYSTEM</u>

a. See Par 5H for pump aspects.

b. <u>Radiation</u>

1) Is circuit temperature scheduled?
   Provided with automatic shut-down?
   Can pumping volume & discharge pressure be reduced?
2) Are radiation and perimeter cooling ever in simultaneous operation?
3) Is hot water generated in a converter or boiler?

c. <u>Hot Water Coils</u>

1) Is circuit temperature scheduled?
2) Dual temperature coils? (i.e. HW winter, Ch.W. summer)

d. See EQ-M for testing and balancing aspects.

ECO RELATED QUESTIONS (EQ)

E.7. CHILLED WATER DISTRIBUTION SYSTEM

a. Pumping Systems

1) See Par 5H for pump aspects.
2) Can utilization apparatus and controls be modified to:

    (a) Change constant volume pumping (CVP) to variable volume (VVP) by converting 3-way valves to 2-way; or by eliminating pressure relief by-pass -- when coil control is mandatory.
    (b) Change to variable speed pumps (VSP) or sequential pumping.
    (c) Change building Secondary System to Terminal Boosting (series instead of hydraulic isolation pumping).

b. Can system T.D. be increased above present level? Can chilled water supply temperature be raised? Number of rows in cooling coils?

c. Are chillers headered together for sequential operation? Are they set for the same LWT? Does utilization apparatus require different levels of LWT? If not headered, and each operates down to low % F.L. is it easy to header them?

d. Is well water employed for any purpose, presently? Can it be adapted to supplement mechanical refrigeration? What is summer water supply temperature?

e. See Par E.3. for refrigeration plant aspects.

f. See EQ-M for testing and balancing aspects.

E.8. ALL-AIR HVAC SYSTEMS

a. Reheat Systems

1) Specifically for humidity control?

ECO RELATED QUESTIONS (EQ)

What is high limit and range?

2) Is humidistat used?
3) Scheduled discharge temperature off cooling coil? How is it controlled?
4) How many reheat zones & how many partitioned spaces per zone?
5) Single, multiple or common area (i.e. corridor) control?
6) Maximum, minimum and average CFM per diffuser. Does system lend itself to Variable Air Volume (VAV) or VAV-reheat conversion?

   (a) Type diffusers?
   (b) Fan control?
   (c) Outside air (OA) control?
   (d) Minimum Supply Air required?

7) Supplementary radiation at perimeter glass areas?
8) Ceiling return air plenum?
9) Are room stat settings raised during cooling cycle and lowered during winter cycle? Evaluate effect on reheat and refrigeration.

b. <u>Dual Duct (DD) and Multizone System</u>

1) Is hot deck parallel flow or pure reheat?
2) Any humidistat control? Is there a required high limit?
3) Scheduled hot and/or cold deck temperature? How is it controlled?
4) How many mixing boxes or zones?
5) Any spill from hot or cold deck?
6) Maximum, minimum and average CFM per diffuser. VAV or VAV-DD conversion?

   (a) Type diffusers
   (b) Fan Control
   (c) OA control
   (d) Minimum supply air required?
   (e) Type and mfr of mixing box and control?

7) Is there any excess static pressure available at end of ducts?

ECO RELATED QUESTIONS (EQ)

c. Outside Air Requirements

1) Can present minimum quantities be reduced?
2) Are dampers open during morning warm-up or cool-down, or during cleaning hours?
3) Refer to EQ-E.12. for interface with exhaust systems.
4) Can uncontaminated purge air be used as make-up for exhasut in other areas (i.e. garage, kitchen areas).
5) Is air balance of outside and exhaust positive or negative?

d. Fan Operation

1) Can fan or duct mains be cycled "On-Off" in any acceptable pattern during normal occupancy for limited VAV effect (without concern about diffusers)? Also for use where large fans are kept running for HVAC of only small % of area during many hours/year.
2) See EQ-M for testing and balancing aspects.
3) If air supply is required for night heating, is fan cycled by thermostat?
4) If fans are operating during unoccupied period, is this necessary?
5) If HVAC system is used only periodically (e.g. for a conference room, or auditorium) is it activated only when required?

ECO RELATED QUESTIONS (EQ)

E.9. AIR-WATER HVAC SYSTEMS

a. Induction Type Perimeter System

1) Do controls and physical arrangement of primary air connections lend themselves to VAV-Induction conversion?

2) Is seasonal changeover and air-water scheduling profile available for the annual range of ambient temperature?

3) Define air-water zoning and control mode.

4) When is primary air system shut-off? Is it operated any time for off-hour heating?

5) % outside air (OA) in primary air system? CFM OA/SF?

6) Fan HP and static pressure.

7) Describe HVAC system used in interior spaces.

ECO RELATED QUESTIONS (EQ)

E.10. ALL-WATER HVAC SYSTEM

a. Does the fan-coil unit provide the entire cooling for the space or is there a supplementary air system, as well? Are the controls interlocked to prevent simultaneous heating and cooling?
b. Are units controlled by water or air volume, or strictly manual? Multi-speed fans?
c. If units have 3-way valves can system and pumps be adapted to throttling control for pumping energy savings?
d. Are fans powered by separate electric risers which lend themselves to remote shut-down and cycling?

E.11 MULTIPLE UNIT AND UNITARY HVAC SYSTEMS

a. Are units air or water cooled? If cooling tower coolant is used, can CWT be lowered?
b. Are units draw-through reheat, double deck or single-zone? If fixed air discharge control is used, is scheduling indicated?
c. Do any of the questions in EQ E-8 concerning system type apply?
d. Are occupancy and function of areas served adaptable to unit cycling?

ECO RELATED QUESTIONS (EQ)

E.12. VENTILATION AND EXHAUST SYSTEMS

a. Make-Up Air Systems

1) Tempering only (i.e. supplied at 50 to 70° F), or for heating also?

2) Coordinated with exhaust system for all operating conditions?

   (a) Constant air volume or variable?
   (b) Modulated or 2-position?
   (c) Degree of air balance attained.

3) Is it strictly outside air? Is there a possibility of drawing air from nearby uncontaminated purge or relief device at tempered, cooled or heated condition?

4) Are any units non-essential? Can it be shut-shut-off during normal occupancy or off-hour cycle? Can it be modulated in balance with reduced exhaust during part load of process or function requiring exhaust?

5) In areas which have high interval heat gains (i.e. machinery and boiler rooms), is make-up air and exhaust designed for optimum "wiping" of hot occupied areas, then hot unoccupied areas? Can final exiting warm air be used for direct, controlled heating of exposed area, entrances, or for reduction of prime heating energy requirements of the make-up air? Dampered blending?

6) Is tempered discharge condition properly controlled for optimum cooling and minimum heat application when supplied to space with variable cooling and/or heating load?

b. Exhaust Systems

1) Are they coordinated, as described in EQ-E.12.a?

ECO RELATED QUESTIONS (EQ)

2) Is exhaust VAV controlled when used for processes or functions which do not require design volume during all operating periods?

3) Can capture area and/or velocity be changed without detriment to the process or function being ventilated thereby permitting an air flow reduction?

   (a) Can tanks be equipped with operable covers, or surface area decreased with floating pellets?
   (b) Can capture velocity and hood configuration be modified to increase exhaust efficiency and so reduce air volume?

ECO RELATED QUESTIONS (EQ)

E.13. OTHER HVAC SYSTEM CONSIDERATIONS

a. Humidification

1) How necessary is it? Can % RH be reduced?
2) Is it applied in systems with large quantities of make-up air?
3) If spray type, is it air, steam or mechanically atomized, and can it substitute evap. cooling for some refrigeration?

b. Coil Freeze Protection

1) Are chilled water coils drained during winter, glycol filled, or are preheaters used?
2) How important is it to have cooling coils available for use for warm spells during heating season?

ECO RELATED QUESTIONS (EQ)

F. PLUMBING SYSTEMS

F.1. Service Hot and Cold Water Systems

a. Is cold water stored or continually pumped? Is it treated?
b. Is it stored in an elevated or a pneumatic tank?
c. If pumped continually (hot or cold water), are pumps sequenced, or speed controlled? Are they controlled automatically? If so how?
d. Is supply pressure to building ever in excess of building pressure requirements? Is this characteristic optimized with minimum or no pumping energy?
e. Are utilization fixtures and equipment pressure, flow or blend - controlled? On cold water? On hot water? Are there a large number of such fixtures?
f. Is hot water system centralized? If so:

   (1) Is supply temperature above 120° F? Why?
   (2) Is storage temperature above supply temperature, at same temperature, or is system instantaneous?
   (3) Is recirculation loop used? Pump control?

g. Are hot water storage tanks insulated? Adequately?
h. Is more than one supply temperature required and provided by local blending? What % of flow is used at distribution temperature?
i. Fired or unfired heat generators? Separate from other building heating systems? How controlled?
j. See EQ-6, pumping.

ECO RELATED QUESTIONS (EQ)

F.2. COMPRESSED AIR SYSTEMS

a. Are there any above 15HP? Other than for control air?

b. Are there many utilization stations served with substantially higher pressure than equipment requires? What % of use on any one distribution system is at the distribution pressure?

c. Are multiple compressors scattered? Headered together?

d. Are compressors capacity controlled or "Start-Stop"?

e. What type of drier is installed?

f. Is intake air taken from coolest available source?

g. With multiple pressure demands, are physical separations of each pressure level substantial? Does present piping lend itself to pressure segregation?

h. Are shut-down procedures for compressors, branch mains, and individual equipment stations sensitive to daily and/or periodic no-load situations?

i. List functions for compressed air use. Is one of them personnel cleaning?

j. Is maintenance adequate to control leakage? Is system periodically tested?

F.3. WASTEWATER SYSTEMS

a. See EQ-K.3., hot effluent

b. Is all effluent accepted by municipal sewage plant without rate penalty? If not, can treatment be justified?

ECO RELATED QUESTIONS (EQ)

G. PUMPING SYSTEMS

G.1. Pumping & Storage (once-through,open systems)

a. Is any portion of available source pressure dissipated by filling a vented storage tank which is at an elevation less than the equivalent head of the source pressure? During what % of total usage hours is source pressure in excess of tank elevation? What is pump hp and total annual quantity of pumped water?

G.2. Pumping Capacity Control (on-line)

a. Does system have a large variation in flow demand and/or pressure? How is this presently accomodated?

(1) By pump sequency?
(2) By speed control of pump?
(3) By choke valve on, or by-pass at pump?
(4) By relief valve at end of distribution system? Pressure setting?
(5) By constant pressure control?
(6) By throttling or 3-way by-pass at terminal equipment?

b. Is distribution system looped, radial, direct or reverse return?

c. What is lowest available pressure at end of the governing circuit at full flow? Is it higher than required?

d. Is it possible to develop a pressure profile of the distribution system with instruments in current use?

G.3. Impeller Shaving

a. With single-pump systems or those in which sequencing or speed control cannot be justified, is there enough excess pressure or flow

ECO RELATED QUESTIONS (EQ)

capacity to justify impeller shaving or dropping the fixed,set spped of a turbine governor?

b. Has system been tested and balanced (TAB) without throttling of pump discharge valve and/or final branches? If not, check need for reduction of pumping capacity after TAB has been done without needless throttling.

ECO RELATED QUESTIONS (EQ)

H. COOLANT SYSTEMS

H.1. General

a. Are water usages automatically capacity controlled at utilization points?
b. Is any heat recovered?
c. Refer to EQ-G, pumping.
d. Is current coolant system causing fouling problems with resultant high maintenance costs.
e. Is any current cooling function being conducted with refrigerated supply that can be handled some substantial portion of the time with air or evaporative cooling systems?

H.2. Once-Through (non-recirculating)

a. Is source a utility supply or site originated (e.g. well or river)?
b. Were well water inquiries ever made of State Geological?
c. If well supply is available, what is annual supply temperature range? What type of cooling is it being used for? What is annual range of effluent temperature? Is well water potable? Is it treated? If treated, describe. Is settling tank used? Is it contaminated in process? Is any reclaimed for other than coolant use after use as coolant? Annual quantity used?
d. Describe coolant function(s).

H.3. Recirculating Systems

a. What type of heat rejection is used? Entering and leaving temperatures?
b. Is it winterized? How?
c. Is system chemically treated? What is blowdown rate? Is water strained by separation process? Is chromate recovered?

ECO RELATED QUESTIONS (EQ)

I. INDUSTRIAL PROCESS SYSTEMS

I.1. General

a. Identify each process (whether it involves single equipment or groups) that has significant energy demands.

   1) Identify energy flows which interface with the foregoing energy system classifications and those which are distinctly separate.

b. What special energy requirements, implications or seemingly necessary energy wastes are involved?

c. Especially identify and quantify processes which have:

   1) Effluent streams above 300° F.
   2) Energy systems which are not contaminated by the process
   3) Substantial hours of operation for processes wich must be kept at operating temperature levels during stand-by, for legitimate process criteria.
   4) Substantial energy consumers with minimal or no automatic capacity control.
   5) Measurable products that can be programmed for Energy Index Management (i.e. Btu/unit of product)
   6) Batch operations requiring alternating heating and cooling.
   7) Continuous operation with high loading diversity.
   8) Drying operations withoug humidity control of effluent air.
   9) Processes with erratic, sudden, substantial input energy loads for start-up followed by repeated no-load or very reduced load periods.

ECO RELATED QUESTIONS (EQ)

I.2. <u>High Fuel Consumers</u>

a. Refer to EQ-E.1., E.2. and F.2.

b. Are operating details available particularly on following types of energy node characteristics?

1) Unusually high excess air in flue gas.
2) Central high-pressure combustion air supply to multiple units.

I.3. <u>High Steam Consumers</u>

a. Do any processes involve direct steam contact and consequent non-return of condensate?

1) Are vessels insulated and tightly sealed during operation of process cycle?
2) What does effluent stream contain besides steam vapor?

b. Is temperature control with steam fully satisfactory or would process be improved with steadier, more easily controlled medium (i.e. hot water).

ECO RELATED QUESTIONS (EQ)

J. MONITORING, CONTROL AND SURVEILLANCE SYSTEMS

J.1. Do any major energy consuming devices have inadequate instrumentation and/or metering for for at least a daily evaluation of operating characteristics and efficiency?

a. Is any remote or local monitoring and logging being conducted without optimal use of data for operation?

b. Is any instrumentation available which is not being used for recording which might be the source of useful data for optimization?

J.2. Is there a current computerized surveillance or monitoring system?

a. Can its use be adapted to automatic control?

b. What parameters are sensed and how many points are there for each?

ECO RELATED QUESTIONS (EQ)

K. WASTE ENERGY MANAGEMENT AND RECOVERY

K.1. HVAC Systems

a. Activated Carbon Purification

1) Are large quantities of OA required because RA would be impure from non-hazardous standpoint (i.e. high occupancy smoking concentrations)? Do contaminants lend themselves to activated carbon purification?
2) Can purified hot exhaust be recycled for direct heating?

b. Conditioned Air Exhaust

1) Are exhaust ducts and OA intakes close enough for enthalpy wheel or heat pipe recovery?
2) Are quantities of contaminated exhaust large enough or are exhaust ducts far enough away to OA intakes to justify run-around coil recovery? Can existing Ch.W.-HW coils in main air handler be used?

c. Heat Pump

1) Is any mechanical refrigeration required with simultaneous need for heat? Can the heat requirement be satisfied at a 90-115° F heat media temperature level? Is the heat required at scattered locations or concentrated in one area? Is the heat presently provided at a higher temperature level by a media? (Also see Section E.3.e.
2) Is any non-fouling type of continuously flowing effluent at 50 to 90° F available during heating demand periods for use as an internal heat source? Is it compatible in its profile of flow with the low level demands of

ECO RELATED QUESTIONS (EQ)

either HVAC systems or process water preheat requirements?

3) Is the cost of electrical energy relatively low when used for a heat pump compared to that of the current heating source?

K.2. COMBUSTION AIR AND FLUE GAS SYSTEMS

a. List all major combustion devices with flue gas temperature above 250° F. Identify those fired with gas, oil, or other fuels.

   1) Do any of them have excess air above 5%? 100?
   2) Is combustion air preheated?
   3) Can flue gases containing high excess air be conveniently recycled as preheated combustion air?

b. Is there a substantial demand for heat at a temperature level approximately 50° F below that of the flue gas? Is this demand simultaneous to the flue gas emission (e.g. feedwater or combustion air)?

c. Is there a long breeching or stack? Is it insulated?

d. Are heat recovery techniques in current use? What are details & experience?

e. Are flue gas cleaning devices equipped for heat recovery? Has maintenance been difficult?

f. Are any similar flue gas exhausts grouped closely together?

g. See EQ-E.1. and E.2.

ECO RELATED QUESTIONS (EQ)

K.3. HOT LIQUID EFFLUENT

a. List all major liquid effluent or coolant recirculation streams above 100° F. Potable or polluted? What are major pollutants and particulates? What is average annual, high and low temperature?
b. Are there any current recovery techniques? What are details and experience?
c. Can hot and cold effluent be conveniently separated?
d. Are there any heating loads which are simultaneous to the flow of the hot effluent (e.g. preheating of make-up liquid to the process).

K.4. HOT AIR OR GAS EXHAUST

a. Can hot air be directly recycled or blended with outside air (OA) to provide tempering or space heating? Is a heat recovery wheel, heat pipe or run-around coil more appropriate for air or gases?
b. Can hot air be employed as preheated combustion air?
c. Can exhaust rate be reduced by modified process control?
d. List major hot streams above 100° F, and their high and low temperature. Identify pollutants and particulates.
e. If effluent is from process driers, is RH known? Is it automatically controlled?
f. Are heat recovery techniques in current use? List their details and experience.
g. Are similar effluent streams grouped together?

K.5. ENERGY LEAKAGE

a. For processes, energy devices and carriers

ECO RELATED QUESTIONS (EQ)

which should retain heating or cooling media, are there any which suffer characteristic conduction losses or actual substantial leakage? For example:

(1) Vessels without covers.
(2) Vessels with covers which are poor seals.
(3) Heat exchangers, piping, or storage tanks with inadequate or no insulation.

K.6. SOLID WASTE RECOVERY

a. Are any valuable products in waste, currently not being reclaimed?
b. Is the waste from this building alone greater than 2.5 tons/day? What are its major constituents? Is there a daily demand for more than 12,500 lb steam/day (or equivalent hot water), during a substantial portion of the year?

K.7. RESOURCE RECLAMATION

a. Are any useful, valuable or polluted products discharged to the environment? Can they be reclaimed?
b. Are any undergoing treatment at present for environmental reasons, without reclamation and re-use?

ECO RELATEC QUESTIONS (EQ)

L. OPERATION AND MAINTENANCE

L.1. General

a. What is the basic philosphy of O&M?

   1) Preventive, predictive, or emergency maintenance? How extensive are individual equipment maintenance schedules and history of work on each major item of plant?
   2) Equipment kept in operation for insurance of full continuity of service in event of failure of one of several modules? What are the procedures and guidelines for sequencing?
   3) On-going periodic comparison of (a) equipment or (b) plant performance, with historic performance?
   4) Updating of O&M Manuals and as-built records.

b. Investigate plant personnel's appraisal of adequacy of manpower for the proper implementation of O&M procedures for the purpose of assuring reliability and optimization of energy usage. What areas suffer deficiencies? What is needed to correct them?

c. Investigate plant personnel's appraisal of design deficiencies which are not correctible by O&M measures alone or require high capital outlay to correct.

   1) Are they satisfied with the design of the system?
   2) What technical support is available from individuals with a comprehensive understanding of the engineering fundamentals involved in the design of their type of facility?

d. To what extent is their freedom of action in O&M and energy retrofit limited by criteria set down by either management, governing codes or process personnel (i.e. non-economic considerations)? Is a list available of proposed modifications

ECO RELATED QUESTIONS (EQ)

which have been abandoned or shelved because of this?

e. What is the extent of outside contract maintenance?

L.2. Building Cleaning
See EQ-C.2.

L.3. Equipment Cleaning and Chemical Treatment

a. Is fouling evaluated in any other manner than by opening equipment up?
b. What % of heat exchangers are essential, critical or of such a nature that unscheduled repair or cleaning would cause hazard to personnel or costly outage.
c. is current practice considered adequate?

L.4. Testing and Balancing

Are air, gas, vapor and liquid circulating systems balanced for minimum horsepower or energy consumption?

a. Are main flow valves wide open?
b. Are ends of mains at full load at higher than required pressures?
c. Are control valves or dampers at or leading to the end of line terminal devices wide open? What is pressure drop across these end control devices?
d. Have any extensive system changes been made without rebalancing?
e. Who does the balancing and what certification or qualifications does he have?

Appendix 2

APPENDIX 2

ELECTRICAL ENERGY APPRAISAL

A. Definitions of Terms.

General. This HANDBOOK uses the American National Standard Institute Definitions.

Demand Factor. American Standard Definition 35.20.077. "The demand factor is the ratio of the maximum demand of a system to the total connected load of the system." The term "demand factor" is also used with reference to parts of an electrical system as well as the system as a whole.

Load Factor. American Standard Definition 35.10.125. "Load factor is the ratio of the average load over a designated period of time to the peak load occurring in that period." Load factor is usually calculated from the ratio of the kilowatt-hours used in the designated period of time to the kilowatt-hours that would have been used if the peak load which occurred had been used continuously over the entire period.

Load Diversity. American Standard Definition 35.10.121. "Load diversity is the difference between the sum of the peaks of two or more individual loads and the peak of the combined load." Load diversity is commonly expressed either as the diversity factor or the coincidence factor. These factors are reciprocals of each other.

Diversity Factor. American Standard Definition 35.20.078. "The diversity factor is the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system." The diversity factor, by this definition, can never be less than one.

Coincidence Factor. American Standard Definition 35.10.131. "Coincidence factor is the ratio of the maximum coincident total demand of a group of consumers to the sum of maximum power demands of individual consumers comprising the group both taken at the same point of supply for the same time." The coincidence factor, by this definition, can never be greater than one.

Load Curve. American Standard Definition 35.10.127. "Load curve is a curve of power versus time showing the value of a specific load for each unit of the period covered." Most load curves are drawn for either a daily, monthly or yearly time period. All three curves are useful for a complete understanding of the characteristics of the electrical loads at ERDA facilities.

The most significant daily load curve is that which is drawn for the day during which the annual system peak load occurs. In order to obtain data to draw this curve it is often necesssary to collect data each day for a week or more during the time when the peak load is most likely to occur. The term Load Profile is also sometimes used to mean Load Curve.

B. Guideline Values for Electrical Energy Appraisal.

This Appendix contains:

- Range of typical values for lighting and receptacle load density, demand factor and load factors in Table APP2-1.

- Selection guides for the above values in Tables APP2-2 through APP2-5.

- Representative Coincidence Factors in Table APP2-6.

TABLE APP2-1 RANGE OF TYPICAL VALUES FOR LIGHTING & RECEPTACLE LOAD DENSITY, DEMAND & LOAD FACTORS PER SPACE USE FUNCTION

DESCRIPTION	LIGHTING AND RECEPTACLES LOAD DENSITY FLUORES. W/SF	INCANDES. W/SF	DEMAND FACTOR %	LOAD FACTOR %
RESEARCH, DEVELOPMENT AND TEST FACILITIES				
Chemistry Laboratory	1.9-2.2	2.2-2.5	70-80	22-28
Electrical Equipment RD and Test Facility	2.0-2.3	2.3-2.6	20-30	3- 7
Materials RD and Test Facility	3.8-4.1	4.1-4.4	30-35	27-32
Physics Laboratory	1.9-2.2	2.2-2.5	70-80	22-28
Food Equipment Laboratory	1.8-2.1	2.1-2.4	25-30	15-20
Instrumentation	1.8-2.1	2.1-2.4	75-80	12-17
ADMINISTRATIVE FACILITIES				
Office	2.5-3.0	3.0-3.5	50-65	20-35
UTILITIES AND GROUND IMPROVEMENTS				
Electric Power Plant	1.1-1.4	1.4-1.7	55-60	58-63
Stand-by Generator Plant	0.7-1.0	1.0-1.3	75-80	5-10
Substation	0.3-0.6	0.6-0.9	25-30	20-25
Steam Plant-Power	1.1-1.4	1.4-1.7	50-55	30-40
Sewage Treatment Plant	0.3-0.6	0.6-0.9	60-70	15-20
Sewage Pumping Station	0.3-0.6	0.6-0.9	55-60	30-35
Incinerator	0.4-0.7	0.7-1.0	55-60	15-20
Garbage House	- -0.1	0.1-0.3	75-80	20-25
Scrap Salvage Buildings	1.7-2.0	2.0-2.3	35-40	15-20
Outdoor Structures	Determine by load count and time			
Water Treatment Plant	1.4-1.7	1.7-2.0	60-80	15-25
Water Pumping Station	0.8-1.1	1.1-1.4	60-80	15-25
Miscellaneous Structures Water Distribution	0.1-0.2	0.2-0.3	60-65	10-15
Fire Protection Pumping Station	Do not include-operate for test off peak			
Compressed Air Plant	0.5-0.8	0.8-1.1	45-75	20-25
Air Conditioning Plant	0.5-0.8	0.8-1.1	60-70	25-30
SUPPLY FACILITIES				
Storage - Depot	0.4-0.7	0.7-1.0	75-80	20-25
Cold Storage Warehouse - Bulk	0.4-0.7	0.7-1.0	70-75	20-25
Cold Storage Warehouse - Ready Issue	0.4-0.7	0.7-1.0	63-68	30-35
General Warehouse - Bulk	0.1-0.3	0.3-0.9	75-80	23-28
Dehumidified Warehouse - Bulk	0.1-0.3	0.3-0.8	60-65	33-38
Flammables Storehouse - Bulk	0.3-0.5	0.5-0.8	75-80	20-25
Underground Storage - Bulk	0.3-0.5	0.5-0.8	65-70	23-28
General Warehouse	1.0-1.3	1.3-1.6	58-63	23-28

TABLE APP 2-1 (Continued)

DESCRIPTION	LIGHTING AND RECEPTACLES LOAD DENSITY FLUORES. W/SF	INCANDES. W/SF	DEMAND FACTOR	LOAD FACTOR
RESIDENTIAL FACILITIES				
Family Housing - Dwellings	0.5-0.7	0.7-1.1	60-70	10-15
Family Housing - Trailers	0.5-0.7	0.7-1.1	70-75	10-15
Family Housing - Detached Garages	0.3-0.4	0.4-0.6	40-50	2- 4
Barracks	1.9-2.2	2.2-2.5	30-35	40-45
Toilet	0.9-1.2	1.2-1.5	75-80	20-25
Laundry	1.9-2.3	2.3-2.8	30-35	20-25
Detached Garage	0.3-0.4	0.4-0.6	40-50	2- 4
Fire Station	0.9-1.1	1.1-1.5	25-35	13-17
Police Station	1.7-2.0	2.0-2.3	48-53	20-25
Gatehouse	1.6-1.9	1.9-2.2	70-75	28-33
Bakery	3.1-3.4	3.4-3.7	30-35	45-60
Locker Room	0.3-0.6	0.6-0.9	75-80	18-23
Laundry and Dry Cleaning Plant	1.9-2.3	2.3-2.8	30-35	45-60
Dependent School - Nursery	1.5-1.8	1.8-2.1	75-80	10-15
Dependent School - Kindergarten	1.5-1.8	1.8-2.1	75-80	10-15
Dependent School - Grade	1.6-1.9	1.9-2.2	75-80	10-15
Dependent School - High	1.7-2.0	2.0-2.3	65-70	12-17
Chapel	0.4-0.7	0.7-1.0	65-70	5-25
Exchange	1.7-2.0	2.0-2.3	60-75	25-32
Bank	2.5-2.9	2.9-3.1	75-80	20-25
Commissary	1.7-2.0	2.0-2.3	55-60	25-30
Cafeteria - Restaurant	1.1-1.4	1.4-1.7	45-75	15-25
Filling Station	2.3-2.6	2.6-2.9	40-60	15-20
Post Office	2.6-2.9	2.9-3.2	75-80	20-25
Hobby Shop	3.1-3.4	3.4-3.7	30-40	25-30
Bowling Alley	1.2-1.5	1.5-1.8	70-75	10-15
Gymnasium	1.2-1.5	1.5-1.8	70-75	20-45
Skating Rink	1.2-1.5	1.5-1.8	70-75	10-15
Field House	1.8-2.1	2.1-2.4	75-80	7-12
Indoor Swimming Pool	1.2-1.5	1.5-1.8	55-60	25-50
Recreation Building	1.4-1.7	1.7-2.0	75-80	15-25
Theatre	13.5-14.5	14.5-15.5	45-55	8-13
Club	2.2-2.5	2.5-2.8	55-60	15-20
Museum	1.2-1.5	1.5-1.8	75-80	30-35
Library	1.2-1.5	1.5-1.8	75-80	30-35
Club House (Golf)	0.3-0.6	0.6-0.9	75-80	15-20
Bus Station	1.2-1.5	1.5-1.8	80-85	30-35
Retail Warehouse	0.9-1.2	1.2-1.5	58-63	23-28
Educational Center	1.3-1.6	1.6-1.9	70-75	30-35
Outdoor Recreation	Determine by load count and time			
Swim Pool - Outdoor	0.2-0.3	0.3-0.4	80-85	20-25

TABLE APP 2-1 (Continued)

DESCRIPTION	LIGHTING AND RECEPTACLES LOAD DENSITY FLUORES. W/SF	INCANDES. W/SF	DEMAND FACTOR	LOAD FACTOR
MAINTENANCE AND PRODUCTION FACILITIES				
Shops Central Tool	2.1-2.4	2.1-2.4	32-37	23-28
Sheet Metal	1.3-1.6	1.6-1.9	10-15	15-20
Forge and Blacksmith	0.9-1.2	1.2-1.5	25-30	13-18
Machine	6.9-2.2	2.2-2.5	16-21	21-26
Boiler	1.2-2.5	1.5-1.8	12-17	14-19
Electric	2.2-2.5	2.5-2.8	33-38	20-25
Pipe and Copper	1.3-1.6	1.6-1.9	22-27	17-22
Electronics	2.0-2.3	2.3-2.6	50-55	23-28
Paint	1.0-1.3	1.3-1.6	50-55	23-28
Foundry	1.2-1.5	1.5-1.8	35-40	22-27
Pattern	3.7-4.0	4.0-4.3	28-33	12-17
Sand Blast	1.7-2.0	2.0-2.1	30-35	10-15
Construction Equipment Maintenance	2.3-2.6	2.6-2.9	35-45	20-25
Railroad Equipment Maintenance	1.6-1.9	1.9-2.2	35-45	15-20
Battery	1.7-2.0	2.0-2.3	55-65	20-25
Public Works or Maintenance	2.2-2.5	2.5-2.8	32-38	18-22
MG Sets - Welding			35-38	16-21
MG Sets - DC Generation			25-35	15-20
Automotive Vehicle Maintenance Facility	2.6-3.5	3.5-3.9	55-65	20-25
Quality Evaluation Laboratory	2.6-2.9	2.9-3.2	55-65	22-27
Other Laboratory	2.3-2.6	2.6-2.9	55-65	22-27
Miscellaneous Production	1.2-1.5	1.5-1.8	35-40	10-15
Asphalt Plant	0.8-1.1	1.1-1.5	75-80	7-12
Concrete Batching Plant	0.8-1.1	1.1-1.4	75-80	15-20
Rock Crusher Plant	0.8-1.1	1.1-1.4	75-80	15-20
Sawmill	0.4-0.7	0.7-1.0	45-55	15-20
Print Shop	2.7-3.0	3.0-3.3	45-55	25-30
MEDICAL FACILITIES				
Hospital	1.1-1.4	1.4-1.7	38-42	45-50
Station Hospital	1.6-1.9	1.9-2.2	38-42	47-52
Clinic	3.5-3.8	3.8-4.1	32-37	20-25
Laboratory	2.0-2.3	2.3-2.6	32-37	20-25
Dental Clinic	3.0-3.3	3.3-3.6	35-40	18-23
Dispensary	1.9-2.2	2.2-2.5	45-50	20-25

TABLE APP 2-2 SELECTION GUIDE:

LIGHTING AND RECEPTACLE LOAD DENSITY

Select factors in the <u>UPPER HALF</u> of the range for the conditions described. GENERAL GUIDES - Facilities lighted to levels at IES values modified per FEA directive. - Shops, offices, warehouses with many small hand tools or office-type machines.
Select factors in the <u>LOWER HALF</u> of the range for the conditions described. GENERAL GUIDES - Heavy machine shops, casual offices and little used facilities.

TABLE APP2-3

SELECTION GUIDE: DEMAND FACTORS

Select factors in the UPPER HALF of the range for the conditions described below:	Select factors in the LOWER HALF of the range for the conditions described below:
GENERAL GUIDES - Facilities in active use and approaching maximum capacity. - Loads predominately lighting. - Loads predominately heating. - Loads dominated by one or two large motors.	GENERAL GUIDES - Facilities for intermittent use or not being fully utilized. - Motor loads made up of a number of independently operated small motors. - Motor loads controlled automatically unless control depends upon weather conditions.
RESEARCH DEVELOPMENT AND TEST FACILITIES - Facilities used for repetitive testing of material or equipment.	RESEARCH DEVELOPMENT AND TEST FACILITIES - Intermittent use
ADMINISTRATIVE FACILITIES - Large administration buildings with mechanical ventilation and air conditioning. Note: group large administrative buildings separately only when administration is a significant part of the total activity load	ADMINISTRATIVE FACILITIES - Casual offices, offices used infrequently by foremen and supervisors or where there is little prolonged desk work.
UTILITIES AND GROUND IMPROVEMENTS - Central heating plants serving large areas and many buildings. - Water pumping stations serving large areas or carrying most of the load of the water system. - Central station compressed air plants.	UTILITIES AND GROUND IMPROVEMENTS - No special guides.
SUPPLY FACILITIES - Refrigerated warehouses in the South. - Dehumidified warehouses in the Mississippi Valley and along seacoasts. - Warehouses for active storage.	SUPPLY FACILITIES - Warehouses with many items of electric driven materials handling equipment including cranes and elevators.
MAINTENANCE AND PRODUCTION FACILITIES - Shops and facilities when engaged in mass production of similar parts.	MAINTENANCE AND PRODUCTION FACILITIES - Intermittent use

TABLE APP2-4

SELECTION GUIDE: LOAD FACTORS

Select factors in the UPPER HALF of the range for the conditions described below:	Select factors in the LOWER HALF of the range for the conditions described below:
GENERAL GUIDES - Facilities operated on two or more shifts. - Loads that are primarily fluorescent lighting. - Many small independently operated motor loads. - Electronic equipment continuously "on" and ready for immediate use. - Cooling and dehumidification loads for year-round climate control in southern climates. - Retail-type service loads and loads that are in active use.	GENERAL GUIDES - Facilities used intermittently. - Inactive facilities. - Large motor loads when the load consists of a relatively small number of motors. - Wholesale-type service facilities.
RESEARCH DEVELOPMENT AND TEST FACILITIES - No special guides.	RESEARCH DEVELOPMENT AND TEST FACILITIES - No special guides.
ADMINISTRATIVE FACILITIES - Large, active, well-lighted offices with ventilation and air-conditioning equipment.	ADMINISTRATIVE FACILITIES - No special guides.
UTILITIES AND GROUND IMPROVEMENTS - Heating plants that supply both heating and process steam. - Water plants with little power load. - Air-conditioning plants for year-round control of environment in the South. - Compressed air plants consisting of many banked compressors operating automatically.	UTILITIES AND GROUND IMPROVEMENTS - Heating plants in the South.
SUPPLY FACILITIES - Refrigerated and dehumidified warehouses in the South or in humid climates. - Warehouses for active storage and in continuous use.	SUPPLY FACILITIES - Refrigerated warehouses in the North. - Warehouses with large materials handling equipment loads.
HOSPITAL AND MEDICAL FACILITIES - Clinics and wards with daily operating hours and in active use.	HOSPITAL AND MEDICAL FACILITIES - No special guides.
HOUSING AND COMMUNITY FACILITIES - Navy exchanges that have food service facilities. - Gymnasiums used in connection with physical therapy. - Barracks at schools and training centers.	HOUSING AND COMMUNITY FACILITIES - Restaurants and exchanges serving one meal a day only. - Restaurants and exchanges with gas or steam food preparation equipment. - Chapels used primarily on Sunday. - Subsistence buildings serving less than 4 meals a day. - Laundries with dry cleaning plants. - Exchanges operated less than 8 hours a day. - Gatehouses operated less than 24 hours a day.
MAINTENANCE AND PRODUCTION FACILITIES - Shops with battery charging equipment operated after hours. - Active shops at full employment. - Mass Production shops.	MAINTENANCE AND PRODUCTION FACILITIES - Welding loads or loads made up primarily of welding equipment. - Job-order workshops. - Shops with large, heavy, special-function machines. - Large induction or dielectric heating loads.

TABLE APP2-5

SELECTION GUIDE:
DEMAND AND LOAD FACTORS - SPECIAL LOADS

Type of Load	Estimated Range of Demand Factor %	Quick Estimating Demand Factor %	Quick Estimating Hours Use		
			One-Shift Operation	Two-Shift Operation	Three-Shift Operation
			Hours Use of Demand	Hours Use of Demand	Hours Use of Demand
Motors: General purposes, Machine Tool, Cranes, Elevators, Ventilation Compressors, Pumps, etc.	20-100	30	1,200	1,600	2,000
Motors: Miscellaneous, Fractional	10-50	25	1,500	1,800	2,100
Resistance Ovens, Heaters & Furnaces	80-100	80	1,000	1,300	1,600
Lighting	65-100	75	2,200	2,800	3,500
Arc Welders	25-50	30	500	700	900
Resistance Welders	5-40	20	500	700	900
Air-Conditioning Equipment	60-100	70	see note 1/		

1/ Hours use of air-conditioning equipment varies from 1200 to 2200 hours depending upon temperature.

TABLE APP2-6 REPRESENTATIVE COINCIDENCE FACTOR VALUES

% Load Factor	Range of Coincidence Factors-%		% Load Factor	Range of Coincidence Factors-%		% Load Factor	Range of Coincidence Factors-%		% Load Factor	Range of Coincidence Factors-%	
	40 Hours Per Week Loads	60 Hours Per Week Loads		40 Hours Per Week Loads	60 Hours Per Week Loads		40 Hours Per Week Loads	60 Hours Per Week Loads		40 Hours Per Week Loads	60 Hours Per Week Loads
1	3	2	26	65	56	51	73	69	76	81	80
2	8	5	27	66	56	52	73	70	77	82	81
3	12	8	28	67	57	53	73	70	78	82	81
4	17	11	29	68	58	54	73	70	79	82	81
5	21	14	30	69	59	55	73	71	80	82	82
6	25	17	31	69	60	56	73	71	81	82	82
7	28	20	32	69	61	57	73	71	82	82	82
8	32	22	33	70	62	58	74	71	83	83	83
9	35	24	34	70	63	59	74	72	84	84	84
10	38	26	35	71	64	60	74	72	85	85	85
11	41	29	36	71	64	61	74	72	86	86	86
12	44	32	37	71	65	62	75	73	87	87	87
13	46	34	38	71	65	63	75	73	88	88	88
14	49	36	39	72	65	64	76	74	89	89	89
15	51	38	40	72	66	65	76	74	90	90	90
16	53	40	41	72	66	66	77	75	91	91	91
17	54	42	42	72	66	67	77	75	92	92	92
18	56	44	43	73	67	68	78	76	93	93	93
19	57	46	44	73	67	69	78	76	94	94	94
20	59	48	45	73	67	70	78	77	95	95	95
21	60	50	46	73	67	71	78	77	96	96	96
22	61	51	47	73	68	72	79	78	97	97	97
23	62	53	48	73	68	73	79	78	98	98	98
24	63	54	49	73	69	74	80	79	99	99	99
25	64	55	50	73	69	75	81	80	100	100	100

NOTE: This Table indicates a theoretical relationship between Load Factors & Coincidence Factors.

Appendix 3

APPENDIX 3

MANUAL ENERGY CALCULATIONS FOR BUILDING 212 AT ARGONNE NATIONAL LABORATORY

A. General. This Appendix demonstrates two alternative procedures for applying the Modified Bin Method to transform climatic hourly occurrences into acceptable EFL* hours. The first procedure uses both dry bulb temperature and wet bulb temperature hourly occurrence frequencies at 5^{o} intervals. These are available in condensed month-by-month tabulations. The second procedure may be used when only mean coincident wet bulb temperatures are available. An example of the development of actual building energy indices using Forms 3-3 and 3-4 is also presented in Section D of this Appendix.

The first procedure is preferred because derivation of the EFL hours is simpler and more precise; the National Weather Service tapes utilized as a primary data source contain wet bulb as well as dry bulb hourly occurrences and are specific for the year under study. The second procedure can be applied in conjunction with the Air Force Weather Data Manual. The Manual is a compilation of average values over a 10-year period, and lists mean coincident wet bulb temperatures rather than hourly wet bulb temperatures. Furthermore, although the Manual provides information on all parts of the country, it treats only a select number of representative stations, whereas a National Weather Service tape may be obtained for a station close to the locality under study. In the event of limited access to either weather tape or computer, the second procedure will yield suitable estimates of EFL hours.

Sections B and C in this Appendix present respectively the recommended and the alternate approaches to EFL hour estimating, through examples relating to conditions in the Argonne National Laboratory area. Note that different weather, design and operating conditions have been adopted in the two examples. These differences are summarized in the following table.

* For all abbreviations in this Appendix, refer to Chapter 3.

SECTION B EXAMPLE: PREFERRED PROCEDURE	SECTION C EXAMPLE: ALTERNATE PROCEDURE
(1) Weather data obtained from Midway Airport Station; wet bulb temperature hourly occurrence frequencies used; climaticdata specific for year under study	(1) Weather data obtained from O'Hare Airport Station; mean coincident wet bulb temperatures used; climatic data are 10-year average values
(2) Correct room and cooling coil LAT conditions used as updated information became available	(2) Uncorrected room and cooling coil LAT conditions used
(3) Operating schedule based upon an occupied period of 8:00 AM to 5:00 PM, to avoid extrapolation and to allow correlation of manual and computerized input data (computer is unable to adapt to 1/2 hour intervals).	(3) Operating schedule based upon an occupied period of 9:00 AM to 5:30 PM; this represents the actual reported operating schedule but adoption of this schedule requires that hourly occurrences be extrapolated to half-hour intervals.

B. Preferred Bin Method Applied to Building 212

B.1 Weather Data. The source of primary data is the National Weather Service tape of climatic conditions at Midway Airport during calendar year 1975. Tables APP3-1 through APP3-6 are the condensed monthly printouts from the weather tape of the dry bulb and wet bulb hourly occurrence frequencies, grouped according to time of day, as follows:

B.1.1 Data for "Dry Bulb Temperature Hourly Occurrences"

Table APP3B-1: "8 AM - 5PM, Occupied Period"
Table APP3B-2: "5 PM - 8AM, Unoccupied Period"
Table APP3B-3: "24 Hour Totals"

B.1.2 Data for "Wet Bulb Temperature Hourly Occurrences"
(Note: Not mean coincident wbt)

Table APP3B-4: "8 AM - 5PM, Occupied"
Table APP3B-5: "5 PM - 8AM, Unocuppied"
Table APP3B-6: "24 Hour Totals"

B.2 Annual Hourly Occurrences. Dry bulb (db) hourly occurrences during operating periods under study, at prescribed room temperatures, may be considered the only essential weather parameters that affect transmission and ventilation sensible heat gains or losses. (Solar loads, affected by sun time, cloud cover orientation, etc. are considered as an additional load above transmission).

Similarly, wet bulb (wb) hourly occurrences at each dry bulb temperature (dbt) bin are sufficient for calculation of latent or total heat gains or losses for ventilation air.

B.3 Operating Conditions

a. Occupancy from 8 AM to 5 PM (taken to permit manual calculation procedures to be on same basis as computer runs).

b. Room design condition maintained 8760 hrs/yr except when cooling equipment has insufficnet capacity to hold 68 dbt.

c. Fixed design cooling coil LAT maintained 8760 hrs/yr with some form of reheat (RHT) employed, to replace reduced internal loads in all cooling (HVAC) units.

B.4 Design Conditions

a. Cooling: Inside 68 dbt/55% RH/51dpt/0.008W
Outside 95 dbt/78wbt/72dpt/0.0168W
Cooling coil leaving air temperature (LAT)
52dbt/51wbt/50.5dpt/0.0078W

b. Heating: Inside 68 dbt; Outside (-4)dbt

B.5 Derivation of Equivalent Full Load Cooling Hours(EFL_c). Table APP3B-7 indicates two bases: one for external SH load calculations of ventilation air or transmission gains with a 68°F room base as applied in Form 3-3, Pg. 1; the other for coil SH load calculations with a 52°F coil LAT base (which includes the total of ventilation and room SH loads on the coil).

B.5.1 Column 2 is based on full load for cooling from the design temperature of 95°F to the room condition of 68°F. The figure for each bin is the cooling load as a decimal portion of full load. Note that the average bin temperatures above 95°F represent greater than 100% full load. Similarly, Column 3 represents the portion of full transmission load from the design temperature of 95°F to the design coil setting of 52°F.

B.5.2 Columns 4 and 5 are from Tables APP3B-1 and APP3B-2.

B.5.3 Columns 6 through 9 are annual energy consumption figures for each bin, where the decimal percent full load x hourly occurrences ≅ annual energy. The annual energy in each of the columns is the same as equivalent full load hours, since EFL hours = (Btu/yr)/(Btuh full load).

An example of the use of these four columns:

> To find the annual transmission gain from 8:00 AM to 5:00 PM for a transmission full load component of 4 Btuh/SF, it is 4 Btuh/SF x Column 6 total.

B.5.4 Similarly the annual energy for any component of load responsive to dbt can be calculated by taking the appropriate group of EFL bins in the appropriate time slot column and multiplying it by the full load for that component.

B.6 <u>Derivation of Equivalent Full Load Heating Hours</u> (EFL_h) Table APP3B-8 indicates two different bases: one for SH load calculations of ventilation loads or transmission losses with a 68°F room base, as applied in Form 3-3, Pg. 5; the other for transmission and ventilation loads with night set-back to room condition of 55°F.

B.6.1 Similar to the above, Columns 2 and 3 represent percent full load for a 68°F room temperature and 55° night set back temperature.

B.6.2 Columns 6 to 9 are the EFL_h hours/year.

B.7 <u>Derivation of Equivalent Full Load Hours for Ventilation</u> (EFL_{vl}) <u>and Coil LH Loads.</u> Table APP3B-9 indicates what appears to be only one base; but Fig. APP3B-1 and APP3B-2 reveal why it serves for both external LH load as well as coil total LH load. The psychrometric plot of design room and coil conditions shows that they are virtually at the same dpt, and therefore the same humidity ratio, W. The figure for the room, W_r was used and it is assumed equal to the coil LAT W_c.

Fig. APP3B-1 is a psychrometric plot of the wbt bins from TAble APP3B-6, with the number in each bin representing the number of hourly occurrences in that bin for the May 1 to Oct. 31 period. All bins which are severed by the 51°F room dpt line, show the hours above 51 dpt prorated to this effective bin area.

The hours below 51 dpt do not represent a LH load on the room or coil - only the dbt hours in Table APP3B-7 impose a load on the coil, which is sensible rather than latent and is effective down to 52°F coil dbt.

B.8 Significance of Load Greater than Design Full Load

B.8.1 It is important to note that the nature of these calculations for annual Btu is predicated upon the supply of no more cooling or heating at any load than that represented by a linear relationship between space load and outside dry bulb temperature or space load and wet bulb Δ h. Since the design load is based upon closed windows and reasonable (new) infiltration control, then if the occupants open windows, or windows age and become leaky, more than the calculated Btu/year will be required. What is even more significant is that, without controls to meter the heat in an exact linear relationship with outdoor temperature, an excessive amount of heat can be added on a year round basis. This can even occur with a room thermostat control, since, for example, the stat might be satisfied with wide open windows by calling for an excessive amount of heat. However, when heat is metered on a high-limit basis with outdoor temperature scheduling, most occupants will close their windows (when they have no control over the setting of the scheduling).

B.8.2 It should be emphasized that the correct procedure for energy consumption calculations is to use the actual hourly occurrence temperature intervals, rather than some arbitrary winter design outdoor condition, for the following reasons:

a. Only equipment sizing and selection is affected by outdoor design criteria, not energy consumption.

When equipment is sized for example at the 97½% winter condition (0° F at Midway), this seldom, if ever, implies that the heating system installed is incapable of heating to a room thermostat setting of, say, 68°F when weather reaches (-20°F). Since heating systems, especially, are almost always oversized, with safety factors, pick-up and stand-by losses, usually without allowance for internal heat credits, it is apparent that they are able to maintain 68°F rooms at -20° or even lower outdoor conditions.

Thus, if the heating system is programmed and controlled to produce 68°F at all times, then its output will match the requirements for whatever outdoor condition exists. The inevitable result is energy consumption which corresponds to the

actual hourly occurrences for actual outdoor conditions, not an arbitrary design outdoor condition taken as -4° F in this case.

b. The above premise is true with regard to correct absolute calculations for annual energy consumption, whether applied to manual or computerized techniques.

c. Not only is the concept valid for absolute energy consumption calculations, but even more so for differential comparisons between alternative designs or operational procedures on the same project. If hourly occurrences actually include periods down to -20° F, any attempt to ignore the occurrences between -4° F and-20° F would result in incorrectly low energy savings when comparing a modified system with an existing system.

d. It should also be noted that the technique developed for this HANDBOOK automatically adjusts for any difference between the 100% Full Load condition assumed and any hourly occurrecne which is at lower than design full load condition. This is what accounts for the full loads greater than 100%. Therefore, as a general rule for energy consumption calculations, it is proper to state that actual climatic tables of hourly occurrences for the specific facility location should be employed in deriving EFL hours, together with full load gain or loss at any assumed design condition, provided more extreme conditions are incorporated at greater than 100% full load values.

TABLE APP3B-1

DATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT

OCCUPIED PERIOD

DRY BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 8AM THRU 5PM

DRY BULB	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANNUAL	
RANGE	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	3	54	6	72	30	66	33	70	0	0	0	0	0	0	0	0	72	68
85/ 89	0	0	0	0	0	0	0	0	18	63	54	69	66	64	24	67	3	67	12	56	0	0	0	0	177	65
80/ 84	0	0	0	0	0	0	0	0	15	65	42	68	96	64	75	66	12	65	3	55	0	0	0	0	243	65
75/ 79	0	0	0	0	0	0	6	44	33	61	65	63	52	61	90	65	27	62	18	52	0	0	0	0	291	62
70/ 74	0	0	0	0	3	52	6	54	67	48	61	61	36	57	61	64	50	55	39	46	15	57	0	0	338	56
65/ 69	0	0	0	0	0	0	18	57	45	50	31	54	23	56	24	64	57	50	40	44	45	54	3	56	286	52
60/ 64	1	57	0	0	3	47	10	54	58	44	32	53	6	55	3	58	59	49	48	44	34	50	18	55	272	48
55/ 59	5	55	0	0	15	37	17	43	37	43	8	52	1	52	0	0	64	44	35	40	30	43	4	51	216	43
50/ 54	1	51	3	33	24	34	46	35	27	44	1	48	0	0	0	0	20	44	64	37	22	41	7	40	215	38
45/ 49	7	45	3	28	23	34	47	34	6	40	0	0	0	0	0	0	6	42	33	37	24	38	4	40	153	36
40/ 44	14	34	3	28	38	29	65	28	1	37	0	0	0	0	0	0	2	39	16	34	29	28	0	0	168	30
35/ 39	62	30	58	26	43	27	36	22	0	0	0	0	0	0	0	0	0	0	2	29	30	26	44	30	275	27
30/ 34	81	23	119	24	81	21	40	23	0	0	0	0	0	0	0	0	0	0	0	0	48	23	151	24	520	23
25/ 29	57	18	31	17	55	15	6	17	0	0	0	0	0	0	0	0	[illegible]	0	0	0	20	22	39	17	208	17
20/ 24	35	16	15	12	19	12	2	17	0	0	0	0	0	0	0	0	[illegible]	0	0	0	3	18	16	14	90	14
15/ 19	21	10	19	5	5	7	1	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	11	50	8
10/ 14	11	2	10	2	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	3	38	2
5/ 9	10	4	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	4
0/ 4	5	1	12	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	21	-5
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-2

OATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT UNOCCUPIED PERIOD

DRY BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 12 M THRU 7AM AND 6PM THRU 11PM

DRY BULB	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		OEC		ANNUAL	
RANGE	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG OPT	NO. HRS	AVG DPT	NO. HRS	AVG DPT	NO. HRS	AVG OPT	NO. HRS	AVG OPT	NO. HRS	AVG OPT	NO. HRS	AVG OPT	NO. HRS	AVG OPT	NO. HRS	AVG DPT
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	3	54	0	0	0	0	3	72	0	0	0	0	0	0	0	0	6	63
85/ 89	0	0	0	0	0	0	0	0	3	46	6	70	24	64	15	69	0	0	0	0	0	0	0	0	48	65
80/ 84	0	0	0	0	0	0	0	0	3	60	33	66	60	64	48	69	9	61	0	0	0	0	0	0	153	66
75/ 79	0	0	0	0	0	0	0	0	9	62	73	66	86	64	123	67	15	62	3	54	0	0	0	0	309	65
70/ 74	0	0	0	0	0	0	9	50	41	60	110	65	132	62	137	64	16	61	21	51	3	58	0	0	469	62
65/ 69	0	0	0	0	6	52	3	56	90	56	62	60	73	59	93	62	84	56	53	50	30	58	0	0	494	58
60/ 64	0	0	0	0	0	0	26	55	59	44	67	52	39	54	15	57	79	50	42	48	59	56	6	54	392	51
55/ 59	4	53	0	0	15	46	25	50	62	43	43	50	17	53	0	0	92	45	49	43	66	46	17	52	390	46
50/ 54	0	0	0	0	15	35	20	36	75	41	26	47	3	50	0	0	76	45	98	43	35	40	14	44	362	42
45/ 49	15	44	9	31	22	36	67	35	81	40	0	0	0	0	0	0	42	41	93	38	30	36	11	42	370	38
40/ 44	23	37	3	31	34	33	82	31	8	36	0	0	0	0	0	0	7	39	62	33	22	32	3	38	244	33
35/ 39	56	31	26	30	56	30	54	25	0	0	0	0	0	0	0	0	0	0	10	32	39	28	55	31	296	29
30/ 34	112	26	172	26	108	23	92	23	0	0	0	0	0	0	0	0	0	0	3	27	78	25	158	25	723	25
25/ 29	82	20	65	20	86	17	27	20	0	0	0	0	0	0	0	0	0	0	0	0	34	20	84	18	378	19
20/ 24	44	17	51	14	53	13	10	14	0	0	0	0	0	0	0	0	0	0	0	0	24	16	41	15	223	15
15/ 19	46	12	17	6	37	6	5	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	11	125	9
10/ 14	19	4	5	3	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	2	40	4
5/ 9	15	3	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	38	2
0/ 4	18	3	30	-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	50	-4
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-3

OATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT 24 HOUR TOTALS

DRY BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 12 M THRU 11PM

DRY BULB RANGE	JAN NO. HRS	JAN AVG DPT	FEB NO. HRS	FEB AVG OPT	MAR NO. HRS	MAR AVG DPT	APR NO. HRS	APR AVG OPT	MAY NO. HRS	MAY AVG DPT	JUN NO. HRS	JUN AVG OPT	JUL NO. HRS	JUL AVG OPT	AUG NO. HRS	AUG AVG DPT	SEP NO. HRS	SEP AVG DPT	OCT NO. HRS	OCT AVG OPT	NOV NO. HRS	NOV AVG DPT	DEC NO. HRS	DEC AVG DPT	ANNUAL NO. HRS	ANNUAL AVG OPT
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	6	54	6	72	30	66	36	71	0	0	0	0	0	0	0	0	78	68
85/ 89	0	0	0	0	0	0	0	0	21	61	60	69	90	64	39	67	3	67	12	56	0	0	0	0	225	65
80/ 84	0	0	0	0	0	0	0	0	18	65	75	67	156	64	123	67	21	63	3	55	0	0	0	0	396	65
75/ 79	0	0	0	0	0	0	6	44	42	62	138	65	138	63	213	66	42	62	21	52	0	0	0	0	600	64
70/ 74	0	0	0	0	3	52	15	52	108	53	171	63	168	61	198	64	66	57	60	48	18	57	0	0	807	60
65/ 69	0	0	0	0	6	52	21	57	135	54	93	58	96	58	117	62	141	54	93	47	75	56	3	56	780	56
60/ 64	1	57	0	0	3	47	36	55	117	44	99	52	45	54	18	57	138	49	90	46	93	54	24	55	664	50
55/ 59	9	54	0	0	30	42	42	47	99	43	51	50	18	53	0	0	156	45	84	42	96	45	21	52	606	45
50/ 54	1	51	3	33	39	34	66	36	102	42	27	47	3	50	0	0	96	45	162	40	57	41	21	43	577	41
45/ 49	22	44	12	31	45	35	114	35	87	40	0	0	0	0	0	0	48	42	126	38	54	37	15	42	523	38
40/ 44	37	36	6	30	72	31	147	30	9	36	0	0	0	0	0	0	9	39	78	33	51	30	3	38	412	32
35/ 39	118	30	84	27	99	29	90	24	0	0	0	0	0	0	0	0	0	0	12	32	69	27	99	30	571	28
30/ 34	193	25	291	25	189	22	132	23	0	0	0	0	0	0	0	0	0	0	3	27	126	24	309	24	1243	24
25/ 29	139	20	96	19	141	16	33	19	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0	0	54	21	123	18	586	18
20/ 24	79	17	66	14	72	12	12	14	0	0	0	0	0	0	0	0	0	0	0	0	27	16	57	15	313	15
15/ 19	67	11	36	5	42	7	6	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	11	175	9
10/ 14	30	3	15	2	3	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	3	78	3
5/ 9	25	3	21	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	55	3
0/ 4	23	3	42	-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	4	71	-4
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-4

DATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT OCCUPIED PERIOD

WET BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 8AM THRU 5PM

DRY BLB RANGE	-36 DN	-35 -31	-30 -26	-25 -21	-20 -16	-15 -11	-10 -6	-5 -1	0 4	5 9	10 14	15 19	20 24	25 29	30 34	35 39	40 44	45 49	50 54	55 59	60 64	65 69	70 74	75 79	80 84	85 89	90 94	95 99	100 104	105 UP
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	24	45	0	0	0	0	0	0
85/ 89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	30	108	36	0	0	0	0	0	0
80/ 84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	84	129	21	0	0	0	0	0	0
75/ 79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	63	111	96	3	0	0	0	0	0	0
70/ 74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	87	126	85	22	0	0	0	0	0	0	0
65/ 69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	60	85	114	24	0	0	0	0	0	0	0	0
60/ 64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	100	109	36	0	0	0	0	0	0	0	0	0
55/ 59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	67	109	25	0	0	0	0	0	0	0	0	0	0
50/ 54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	67	123	19	0	0	0	0	0	0	0	0	0	0	0
45/ 49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	111	24	0	0	0	0	0	0	0	0	0	0	0	0
40/ 44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	92	32	0	0	0	0	0	0	0	0	0	0	0	0	0
35/ 39	0	0	0	0	0	0	0	0	0	0	0	0	0	9	234	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30/ 34	0	0	0	0	0	0	0	0	0	0	0	0	0	309	211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25/ 29	0	0	0	0	0	0	0	0	0	0	0	0	118	90	0	0	0	0	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0
20/ 24	0	0	0	0	0	0	0	0	0	0	0	34	56	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0
15/ 19	0	0	0	0	0	0	0	0	0	0	19	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10/ 14	0	0	0	0	0	0	0	0	0	21	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/ 9	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0/ 4	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-5

DATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT UNOCCUPIED PERIOD

WET BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 12 M THRU 7AM AND 6PM THRU 11PM

DRY BLB RANGE	WET BULB TEMPERATURE RANGES -36 DN	-35 -31	-30 -26	-25 -21	-20 -16	-15 -11	-10 -6	-5 -1	0 4	5 9	10 14	15 19	20 24	25 29	30 34	35 39	40 44	45 49	50 54	55 59	60 64	65 69	70 74	75 79	80 84	85 89	90 94	95 99	1C 104	105 UP
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0
85/ 89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	27	12	0	0	0	0	0	0
80/ 84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	36	81	21	0	0	0	0	0	0
75/ 79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	135	150	0	0	0	0	0	0	0
70/ 74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	30	105	275	56	0	0	0	0	0	0	0
65/ 69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	15	125	249	96	0	0	0	0	0	0	0	0
60/ 64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	95	234	48	0	0	0	0	0	0	0	0	0
55/ 59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	107	206	74	0	0	0	0	0	0	0	0	0	0
50/ 54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	228	66	0	0	0	0	0	0	0	0	0	0	0
45/ 49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	271	78	0	0	0	0	0	0	0	0	0	0	0	0
40/ 44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	172	61	0	0	0	0	0	0	0	0	0	0	0	0	0
35/ 39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30/ 34	0	0	0	0	0	0	0	0	0	0	0	0	0	385	338	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25/ 29	0	0	0	0	0	0	0	0	0	0	0	0	189	189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20/ 24	0	0	0	0	0	0	0	0	0	0	0	76	147	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15/ 19	0	0	0	0	0	0	0	0	0	0	37	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10/ 14	0	0	0	0	0	0	0	0	0	15	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/ 9	0	0	0	0	0	0	0	0	2	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0/ 4	0	0	0	0	0	0	0	12	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-6

DATA FOR CHICAGO, ILL. 1975 MIDWAY AIRPORT 24 HOUR TOTALS

WET BULB TEMPERATURE FREQUENCY OCCURRENCE FOR THE TIME PERIOD 12 M THRU 11PM

DRY BULB RANGE	WET BULB TEMPERATURE RANGES -36 DN	-35 -31	-30 -26	-25 -21	-20 -16	-15 -11	-10 -6	-5 -1	0 4	5 9	10 14	15 19	20 24	25 29	30 34	35 39	40 44	45 49	50 54	55 59	60 64	65 69	70 74	75 79	80 84	85 89	90 94	95 99	100 104	105 UP
105 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/ 99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90/ 94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	24	48	0	0	0	0	0	0
85/ 89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	36	135	48	0	0	0	0	0	0
80/ 84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	120	210	42	0	0	0	0	0	0
75/ 79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	87	246	246	3	0	0	0	0	0	0
70/ 74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	117	231	360	78	0	0	0	0	0	0	0
65/ 69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	75	210	363	120	0	0	0	0	0	0	0	0
60/ 64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	195	343	84	0	0	0	0	0	0	0	0	0
55/ 59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	174	315	99	0	0	0	0	0	0	0	0	0	0
50/ 54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	135	351	85	0	0	0	0	0	0	0	0	0	0	0
45/ 49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	382	102	0	0	0	0	0	0	0	0	0	0	0	0
40/ 44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	264	93	0	0	0	0	0	0	0	0	0	0	0	0	0
35/ 39	0	0	0	0	0	0	0	0	0	0	0	0	0	9	450	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30/ 34	0	0	0	0	0	0	0	0	0	0	0	0	0	694	549	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25/ 29	0	0	0	0	0	0	0	0	0	0	0	0	307	279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20/ 24	0	0	0	0	0	0	0	0	0	0	0	110	203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15/ 19	0	0	0	0	0	0	0	0	0	0	56	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10/ 14	0	0	0	0	0	0	0	0	0	36	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/ 9	0	0	0	0	0	0	0	0	2	53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0/ 4	0	0	0	0	0	0	0	12	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5/ -1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10/ -6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15/-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-20/-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-25/-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-30/-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35/-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36 DN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE APP3B-7

DERIVATION OF EQUIVALENT FULL LOAD COOLING HOURS (EFL_C)
FROM MAY 1 TO OCT. 31, 1975 AT MIDWAY FOR 95°F OUTSIDE DESIGN TEMP
68°F ROOM TEMP AND 52°F COOLING COIL LEAVING AIR TEMP

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
OUTDOOR TEMP BIN	DECIMAL % OF FULL LOAD AT BIN MID-POINT		HOURLY OCCURRENCES 5/1 TO 10/30		BTU/YR PER BTUH DESIGN LOAD OR EQUIVALENT F.L. CLG HRS/YR			
					FOR 95°-68°LOAD TRANS OR VENT SH		FOR 95°-52° LOAD COOLING COIL	
	TO ROOM $\Delta T/(95-68)$	TO COIL $\Delta T/(95-52)$	8:00 AM TO 5:00 PM	5:00 PM TO 8:00 AM	8:00 AM TO 5:00 PM	5:00 PM TO 8:00 AM	8:00 AM TO 5:00 PM	5:00 PM TO 8:00 AM
52/54	-	0.035	67	167	-	-	2	5
55/59	-	0.128	145	263	-	-	18	33
60/64	-	0.244	206	301	-	-	50	73
65/69	-	0.360	220	455	-	-	79	163
70/74	0.167	0.477	314	457	52	76	149	218
75/79	0.352	0.593	285	309	100	108	169	183
80/84	0.537	0.709	243	153	130	82	172	108
85/89	0.722	0.826	177	48	127	34	146	39
90/94	0.907	0.942	72	6	65	5	67	5
95/99	1.093	1.058	0	0	0	0	0	0
100/104	1.278	1.174	0	0	0	0	0	0
TOTAL IN 68°-99° BIN			777	516	476	307		
24 HOUR TOTAL			1293		783			
TOTAL IN 52°-99° BIN			1729	2159			855	831
24 HOUR TOTAL			3888				1687	

TABLE APP3B-8

DERIVATION OF EQUIVALENT FULL LOAD HEATING HOURS (EFL_h)
FOR CALENDAR YEAR 1975 AT MIDWAY
FOR ROOM TEMPERATURES AT
68°F AND 55°F AND (-4°F) OUTSIDE DESIGN TEMPERATURE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
OUTDOOR TEMP RANGE °F	DECIMAL % OF FULL LOAD AT MIDPOINT		HOURLY OCCURRENCES		BTU/YR PER BTUH DESIGN LOAD OR EQUIVALENT FL HTG HRS/YR			
					FOR 68°F-(-4°) LOAD		FOR 55°-(-4°)LD	
	TO RM AT 68° ΔT /[68-(-4)]	TO RM AT 55° ΔT/[55-(-4)]	8:00AM 5:00PM	5:00PM 8:00AM	8:00AM 5:00PM	5:00PM 8:00AM	8:00AM 5:00PM	5:00PM 8:00AM
60/64	0.076	-	272	392	20	29	-	-
55/59	0.146	-	216	390	31	56	-	-
50/54	0.215	0.042	215	362	46	77	9	15
45/49	0.285	0.127	153	370	43	105	19	46
40/44	0.354	0.212	168	244	59	86	35	51
35/39	0.424	0.297	275	296	116	125	81	87
30/34	0.493	0.381	520	723	256	356	198	275
25/29	0.563	0.466	208	378	117	212	96	176
20/24	0.632	0.551	90	223	56	140	49	122
15/19	0.701	0.[illegible]36	50	125	35	87	31	79
10/14	0.771	0.720	38	40	29	30	27	28
5/9	0.840	0.805	17	38	14	31	13	30
0/4	0.910	0.890	21	50	19	45	18	44
-5/-1	0.979	0.975	0	0	0	0	0	0
TOTALS FOR ROOM AT 68°F			2243	3631	846	1387	-	-
24 HOUR TOTAL			5874		2234		-	
TOTALS FOR ROOM AT 55°F			1755	2849	-	-	581	959
24 HOUR TOTAL			4604		-		1541	

TABLE APP3B-9

DERIVATION OF EQUIVALENT FULL LOAD HOURS FOR VENTILATION & COIL LH LOADS FROM MAY 1 TO OCT. 31, 1975 AT MIDWAY FOR 95 DBT/78 WBT OUTSIDE, 68 DBT/55% RH ROOM & 52 DBT/51 WBT COIL

(1) OUTDOOR WBT BIN	(2) OUTDOOR DBT BIN	(3) W_o (LB/LB) AT MID-POINT OF BIN	(4) ΔW TO ROOM $(W_o - W_r)$ AT W_r=0.008	(5) DECIMAL % OF FULL LH LOAD TO RM $W_o - W_r / 0.0088$	(6) HOURLY OCCURRENCE ABOVE W=0.008	(7) EFL HOURS OUTSIDE AIR LH VENTILATION LOAD TO ROOM
75/79	90/94	.0170	.0090	1.02	48	48
	85/89	.0181	.0101	1.15	48	55 *
	80/84	.0193	.0113	1.28	42	53
	75/79	.0195	.0115	1.31	3	3
70/75	90/94	.0125	.0045	0.51	24	12
	85/89	.0138	.0058	0.66	135	89
	80/84	.0150	.0070	0.80	210	168
	75/79	.0162	.0082	0.93	246	228
	70/74	.0163	.0083	0.94	78	73
65/69	90/94	.0094	.0014	0.16	4	0
	85/89	.0100	.0020	0.23	34	7
	80/84	.0110	.0030	0.34	120	40
	75/79	.0122	.0042	0.48	246	118
	70/74	.0133	.0053	0.60	360	216
	65/69	.0137	.0057	0.65	120	78
60/64	85/89	.0082	.0002	0.02	0	0
	80/84	.0085	.0005	0.06	9	0
	75/79	.0091	.0011	0.13	62	8
	70/74	.0099	.0019	0.22	226	49
	65/69	.0110	.0030	0.34	363	123
	60/64	.0114	.0034	0.39	84	32
55/59	70/74	.0083	.0003	0.03	9	2
	65/69	.0084	.0004	0.05	97	4
	60/64	.0092	.0012	0.14	284	39
	55/59	.0094	.0014	0.16	99	15
50/54	55/59	.0084	.0004	0.05	76	3
	50/54	.0084	.0004	0.05	19	1
TOTAL					3046	1476

* POINT SHOWN ON FIG. 3B-2

FIG APP 3B-1
HOURLY OCCURRENCE BINS FOR VENTILATION AND COOLING COIL LH LOADS

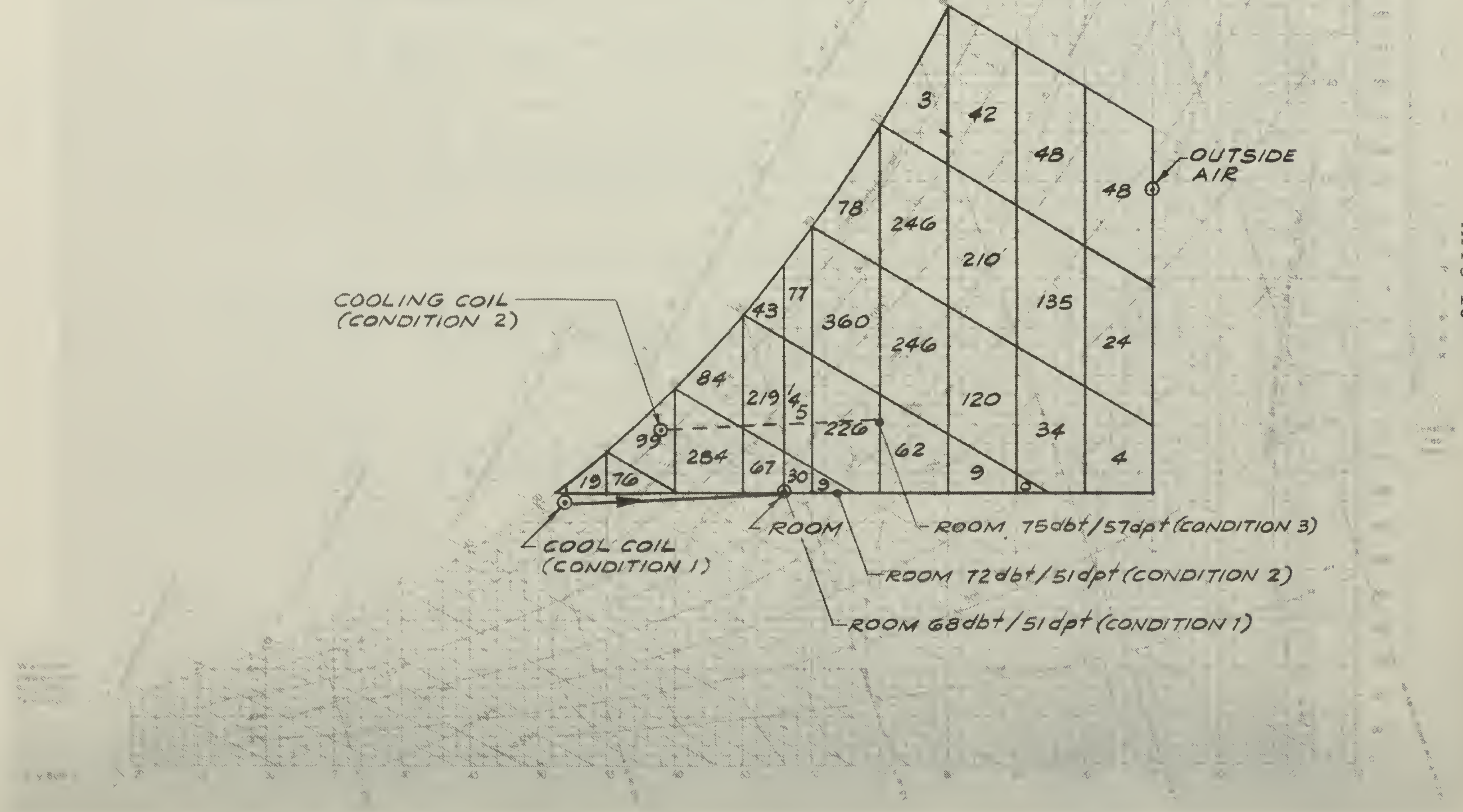


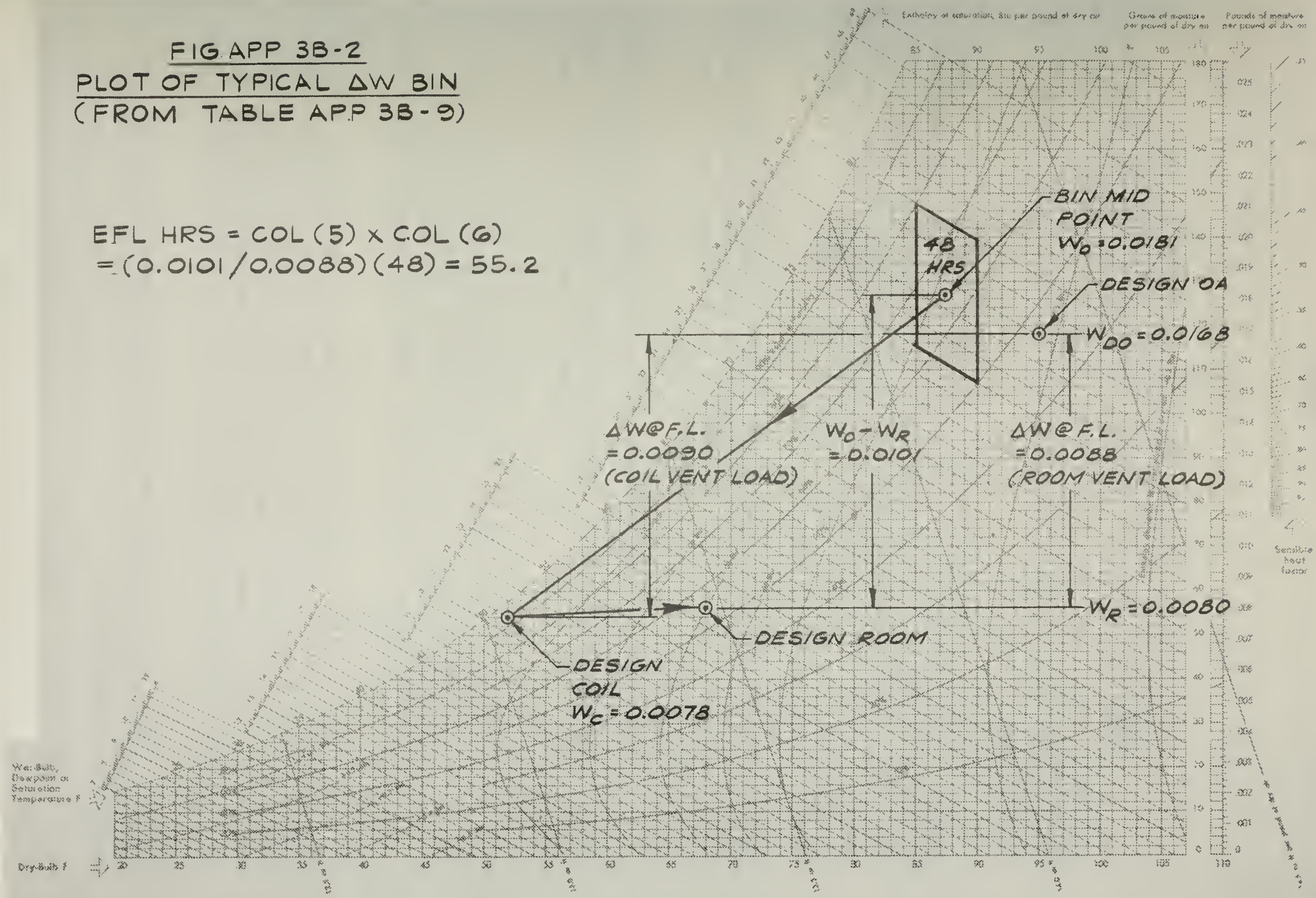
FIG APP 3B-2

PLOT OF TYPICAL ΔW BIN

(FROM TABLE APP 3B-9)

EFL HRS = COL (5) x COL (6)

= (0.0101/0.0088)(48) = 55.2



C. Alternate Bin Method Applied to Building 212

C.1 Weather Data. The source of prime data for this procedure is the dbt hourly occurrence frequencies at 5° intervals and mean coincident wbt for O'Hare Airport, Chicago; from the Engineering Weather Data Manual (AFM 88-8) of the departments of the Air Force, Army and Navy dated 15 June 1976. See Tables APP3C-1 and APP3C-2.

C.2 Annual Hourly Occurrences. For preliminary ECO selection, appraisal and analysis, the mean coincident wbt figures in Tables APP3C-1 and APP3C-2 may be used. This wbt for each db temperature bin, is the average of all wbt readings that month within that bin. Its use, in lieu of actual wb occurrences, reduces the impact of the ECO, on the conservative side (actual energy savings will be greater than those calculated on the basis of mean coincident wbt figures).

The tables are divided into three 8 hour groupings per day, which permits proportioning the occurrences into occupied and unoccupied periods for different room temperature treatment such as day and night temperatures.

C.3 Derivation of Equivalent Full Load Cooling Hours (EFL_c)

C.3.1 Tables APP3C-3 and APP3C-4 convert hourly occurrences to EFL hours based upon the following operating parameters at Building 212.

- Occupancy from 9:00 AM to 5:30 PM
- Room temperature of 75° F maintained 24 hours/day, 365 days/year
- Cooling coil full load = 95° -55° F cooling range
- Transmission and ventilation sensible Load = 95° - 75° cooling range.

C.3.2 Table APP3C-3 shows the raw hourly occurrence data from Table APP3C-1 redistributed on a proportional basis for the periods from 9:00 AM to 5:30 PM to 9:00 AM from April 19 to Oct. 14. This was the actual reported 1975 cooling period. The last three columns, include a prorated deletion for Oct. 15 to Oct. 31 and an addition from Table APP3C-2 for April 19 to April 30.

C.3.3 Table APP3C-4 was derived in the same way as was its counterpart, Table APP3B-7, but on the basis of the actual operating parameters.

C.4 Derivation of Equivalent Full Load Heating Hours (EFL_h)

C.4.1 Table APP3C-5 was derived in a manner identical to

that of its counterpart, Table APP3B-8, but on the basis of a 75°F room temperature, a 55°F night setback temperature, and actual operating schedules.

C.5 Derivation of Equivalent Full Load Ventilation Hours (EFL_V)

C.5.1 Table APP3C-7 shows the hours of occurrence of each mean wbt within each temperature bin, taken from Tables APP3C-1 and APP3C-2. This table is illustrated only down to 45°F dbt for examination of cooling season related, latent ventilation loads. (Since humidification has been discontinued in Bldg. 212 the wbt data was not required below 45° dbt). If heating season humidification analysis were contemplated for any ECO study, this tabulation should be completed.

C.5.2 Subtotals in the last four columns were made for possible analysis of coil related and room temperature related loads. Similarly the bottom totals for 65°F and 55° wbt are for room and coil related use.

C.5.3 Table APP3C-8 considers the wb hourly occurrences only above 75 F ambient because Bldg. 212 is so predominantly 100% OA all year round that the examination of occurrences below 75° dbt (otherwise needed for enthalpy economizer control analysis, the table should be similarly expanded to present the relevant temperature ranges.

C.5.4 Ventilation total heat loads may be used with these EFL hours (sensible + latent) based upon

$$\text{Ventilation TH (Btuh/SF)} \times EFL_V = \text{Btu/SF/yr}$$

TABLE APP3C-1 CLIMATIC DATA

*O'HARE INTERNATIONAL AIRPORT ILLINOIS

Mean Frequency of Occurrence of Dry Bulb Temperature (°F) With Mean Coincident Wet Bulb Temperature (°F) For Each Dry Bulb Temperature Range

COOLING SEASON

Temperature Range (°F)	MAY Obsn/Hour Gp 02 to 09	MAY 10 to 17	MAY 18 to 01	MAY Total Obsn	MAY Mean Coincident Wet Bulb (°F)	JUNE Obsn/Hour Gp 02 to 09	JUNE 10 to 17	JUNE 18 to 01	JUNE Total Obsn	JUNE Mean Coincident Wet Bulb (°F)
100/104							0		0	77
95/99							2		2	78
90/94		1		1	71	0	14	1	15	75
85/89	0	10	0	10	69	2	33	5	40	73
80/84	1	21	8	25	67	9	45	15	69	70
75/79	4	30	7	41	64	23	44	31	98	68
70/74	12	33	18	63	61	41	41	45	127	65
65/69	27	33	27	87	59	49	28	43	120	61
60/64	30	30	28	88	55	46	15	44	105	58
55/59	36	33	40	109	51	33	11	27	71	54
50/54	46	31	44	121	47	25	7	20	52	49
45/49	47	20	46	113	43	10	0	8	18	45
40/44	29	5	28	62	39	2		1	3	41
35/39	14	1	7	22	35					
30/34	2		0	2	31					
25/29										
20/24										
15/19										

Temperature Range (°F)	JULY Obsn/Hour Gp 02 to 09	JULY 10 to 17	JULY 18 to 01	JULY Total Obsn	JULY Mean Coincident Wet Bulb (°F)	AUGUST Obsn/Hour Gp 02 to 09	AUGUST 10 to 17	AUGUST 18 to 01	AUGUST Total Obsn	AUGUST Mean Coincident Wet Bulb (°F)
100/104		0		0	78					
95/99		3		3	79		3		3	74
90/94	0	17	1	18	76	0	19		19	74
85/89	4	50	5	59	73	2	29	3	34	73
80/84	13	69	21	103	71	7	54	9	70	71
75/79	38	57	50	145	69	22	70	35	127	68
70/74	59	38	63	160	66	51	47	63	161	66
65/69	68	12	64	144	63	67	21	70	158	63
60/64	42	2	32	76	59	52	5	43	100	59
55/59	17	0	10	27	55	31	0	18	49	55
50/54	7		2	9	51	13		6	19	50
45/49	0			0	47	3		1	4	46
40/44						0			0	42
35/39										
30/34										
25/29										
20/24										
15/19										

Temperature Range (°F)	SEPTEMBER Obsn/Hour Gp 02 to 09	SEPTEMBER 10 to 17	SEPTEMBER 18 to 01	SEPTEMBER Total Obsn	SEPTEMBER Mean Coincident Wet Bulb (°F)	OCTOBER Obsn/Hour Gp 02 to 09	OCTOBER 10 to 17	OCTOBER 18 to 01	OCTOBER Total Obsn	OCTOBER Mean Coincident Wet Bulb (°F)
100/104										
95/99		2		2	73					
90/94	0	5		5	72					
85/89	0	12	0	12	70		1		1	72
80/84	1	21	2	24	68		12	0	12	67
75/79	5	35	9	49	65	1	16	1	18	64
70/74	15	52	20	87	62	4	26	8	38	61
65/69	32	57	43	132	60	13	36	17	66	59
60/64	54	34	57	145	57	22	40	25	87	55
55/59	42	16	46	104	52	32	41	38	111	51
50/54	39	5	32	76	49	37	43	46	126	47
45/49	30	1	20	51	45	49	18	48	115	43
40/44	15		9	24	40	38	9	31	78	39
35/39	6		2	8	36	29	6	22	57	35
30/34	1			1	31	18	0	10	28	31
25/29						4		2	6	26
20/24						1		0	1	22
15/19						0			0	18

TABLE APP3C-2 CLIMATIC DATA

*O'HARE INTERNATIONAL AIRPORT ILLINOIS

Mean Frequency of Occurrence of Dry Bulb Temperature (°F) With Mean Coincident Wet Bulb Temperature (°F) For Each Dry Bulb Temperature Range

HEATING SEASON

Temperature Range (°F)	NOVEMBER Obsn/Hour Gp 02 to 09	NOVEMBER Obsn/Hour Gp 10 to 17	NOVEMBER Obsn/Hour Gp 18 to 01	NOVEMBER Total Obsn	NOVEMBER Mean Coincident Wet Bulb (°F)	DECEMBER Obsn/Hour Gp 02 to 09	DECEMBER Obsn/Hour Gp 10 to 17	DECEMBER Obsn/Hour Gp 18 to 01	DECEMBER Total Obsn	DECEMBER Mean Coincident Wet Bulb (°F)	JANUARY Obsn/Hour Gp 02 to 09	JANUARY Obsn/Hour Gp 10 to 17	JANUARY Obsn/Hour Gp 18 to 01	JANUARY Total Obsn	JANUARY Mean Coincident Wet Bulb (°F)
100/104															
95/99															
90/94															
85/89															
80/84															
75/79		1		1	65										
70/74	0	2		2	59										
65/69	0	10	2	12	58							0		0	63
60/64	5	12	5	22	56		1	0	1	56		0	0	0	59
55/59	9	19	12	40	52	0	4	2	6	54	0	1	1	2	55
50/54	13	26	17	56	47	3	7	3	13	48	2	2	2	6	50
45/49	19	29	25	73	43	6	11	6	23	43	2	6	3	11	46
40/44	32	37	34	103	38	13	24	14	51	39	5	12	6	23	39
35/39	39	33	41	113	34	33	43	41	117	34	19	39	26	84	34
30/34	48	38	43	129	30	51	60	56	167	30	50	69	57	176	30
25/29	37	19	30	86	25	42	37	39	118	25	45	42	46	133	25
20/24	18	9	16	43	20	32	28	29	89	21	35	27	34	96	21
15/19	12	2	9	23	16	23	14	26	63	16	28	18	25	71	15
10/14	5	1	3	9	11	17	10	11	38	11	22	15	14	51	11
5/9	1	1	1	3	6	11	5	10	26	6	14	10	14	38	6
0/4	1	1	1	3	1	9	3	5	17	1	12	4	12	28	1
−5/−1	1		1	2	−3	4	1	3	8	−3	8	2	6	16	−4
−10/−6						2	0	2	4	−8	4	1	1	6	−8
−15/−11						1		1	2	−14	2	0	1	3	−13
−20/−16						1		0	1	−18	0			0	−18
−25/−21											0			0	−21

Temperature Range (°F)	FEBRUARY Obsn/Hour Gp 02 to 09	FEBRUARY Obsn/Hour Gp 10 to 17	FEBRUARY Obsn/Hour Gp 18 to 01	FEBRUARY Total Obsn	FEBRUARY Mean Coincident Wet Bulb (°F)	MARCH Obsn/Hour Gp 02 to 09	MARCH Obsn/Hour Gp 10 to 17	MARCH Obsn/Hour Gp 18 to 01	MARCH Total Obsn	MARCH Mean Coincident Wet Bulb (°F)	APRIL Obsn/Hour Gp 02 to 09	APRIL Obsn/Hour Gp 10 to 17	APRIL Obsn/Hour Gp 18 to 01	APRIL Total Obsn	APRIL Mean Coincident Wet Bulb (°F)
100/104															
95/99															
90/94															
85/89															
80/84												3		3	64
75/79												11	1	12	63
70/74							1		1	59	2	20	4	26	60
65/69		0		0	60		3	0	3	56	4	22	0	35	56
60/64	0	1		1	55	1	5	2	8	53	14	20	14	48	54
55/59	1	2	1	4	52	2	11	4	17	50	14	24	18	56	50
50/54	2	5	2	9	48	5	18	6	29	46	26	36	32	94	46
45/49	2	8	4	14	43	11	25	15	51	42	34	37	38	100	43
40/44	7	22	10	39	38	19	41	27	87	38	42	35	52	129	38
35/39	23	47	30	100	34	42	55	49	146	34	55	25	39	119	34
30/34	61	64	63	188	30	68	49	68	185	30	31	6	24	61	30
25/29	38	33	46	117	25	40	25	39	104	25	14	1	7	22	25
20/24	25	17	24	66	20	31	10	20	61	21	3	0	2	5	20
15/19	22	8	15	45	16	17	4	12	33	16	1			1	16
10/14	15	6	7	28	11	9	1	4	14	11					
5/9	8	5	7	20	6	2	0	2	4	6					
0/4	9	5	6	20	1	1	0		1	2					
−5/−1	6	1	7	14	−4										
−10/−6	4		2	6	−8										
−15/−11	1		0	1	−13										
−20/−16	0			0	−16										
−25/−21															

Temperature Range (°F)	ANNUAL (TOTAL—ALL MONTHS) Obsn/Hour Gp 02 to 09	ANNUAL Obsn/Hour Gp 10 to 17	ANNUAL Obsn/Hour Gp 18 to 01	ANNUAL Total Obsn	ANNUAL Mean Coincident Wet Bulb (°F)
100/104		0		0	77
95/99		10		10	76
90/94	1	56	1	58	75
85/89	9	135	13	157	72
80/84	31	221	51	303	68
75/79	93	264	135	492	66
70/74	185	259	222	666	62
65/69	260	225	275	760	60
60/64	267	166	251	684	56
55/59	217	162	217	596	53
50/54	217	178	213	608	48
45/49	214	158	211	583	44
40/44	203	185	212	600	39
35/39	260	250	258	768	34
30/34	326	286	321	933	30
25/29	220	157	210	587	25
20/24	145	91	124	360	21
15/19	102	46	86	234	16
10/14	68	32	39	139	11
5/9	36	22	34	92	6
0/4	32	12	24	68	1
−5/−1	20	4	17	41	−3
−10/−6	9	1	5	15	−8
−15/−11	4	0	1	5	−13
−20/−16	1		0	1	−17
−25/−21				0	−21

TABLE APP3C-3

REDISTRIBUTION OF COOLING SEASON DRY BULB HOURLY OCCURENCES - O'HARE

TEMPERATURE	MAY		JUNE		JULY		AUG		SEPT		OCT		TOTALS 5/1-10/31		ADJUSTED TOTALS 4/19 TO 10/14		
RANGE (OF)	9:00AM 5:30PM	5:30 PM 9:00 AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	GRAND TOTAL 24 HR BASIS
100/104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95/99	0	0	2	0	3	0	3	0	2	0	0	0	10	0	10	0	10
90/94	1	0	15	0	18	0	19	0	5	0	0	0	58	0	58	0	58
85/89	10	0	35	5	52	7	31	3	12	0	1	0	141	51	141	15	156
80/84	23	2	50	19	74	29	56	14	22	2	12	0	237	66	232	66	298
75/79	32	9	49	49	66	79	76	51	37	12	17	1	277	201	272	200	472
70/74	37	26	49	78	50	110	64	97	55	32	28	10	283	353	276	350	626
65/69	40	47	38	82	17	127	34	124	64	68	39	17	232	475	220	465	685
60/64	38	50	15	80	6	70	10	90	45	100	45	42	169	432	154	419	573
55/59	42	67	14	57	2	25	2	47	24	80	48	63	132	339	117	317	434
SUBTOTAL	223	201	277	370	288	447	295	426	266	294	190	143	1539	1881	1480	1832	3312
50/54	43	78	10	42	0	9	9	19	12	64	51	75	116	257	103	237	340
45/49	28	85	2	61	0	0	0	4	4	47	28	87	62	239	63	217	280
40/44	12	50	1	2	0	0	0	0	2	22	16	62	31	136	38	133	171
35/39	3	19	0	0	0	0	0	0	0	8	11	46	14	73	20	78	98
30/34	0	2	0	0	0	0	0	0	0	1	2	26	2	29	5	32	37
25/29	0	0	0	0	0	0	0	0	0	0	0	6	0	6	1	9	10
20/24	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	2
SUBTOTAL	86	234	13	60	0	9	0	23	18	142	108	303	225	741	230	708	938
GRAND TOTAL	309	435	290	430	288	456	295	449	284	436	198	446	1764	2622	1710	2540	4250

TABLE APP3C-4 DERIVATION OF EQUIVALENT FULL LOAD COOLING HRS (EFL$_C$)
FROM APRIL 19 TO OCTOBER 14 AT O'HARE FOR 95°F OUTSIDE DESIGN TEMP
75°F ROOM TEMP & 55°F COOLING COIL LEAVING AIR TEMP.

1	2	3	4	5	6	7	8	9
OUTDOOR TEMP BIN	DECIMAL % OF FULL LOAD AT BIN MID POINT BASE F.L. T		HOURLY OCCURRENCES 4/19 To 10/14		BTU/YR PER BTUH DESIGN LOAD OR EQUIVALENT F.L. CLG HRS/YR			
					FOR 95°-75°LOAD TRANS OR VENT		FOR 95-55 LOAD COOLING COIL	
	95°-75° (TRANSM)	95°-55° (COOL COIL)	9:00 AM To 5:30 PM	5:30 PM To 9:00 AM	9:00 AM To 5:30 PM	5:30 PM To 9:00 AM	9:00 AM To 5:30 PM	5:30 PM To 9:00 AM
55/59		+0.0625	117	317			7	19
60/64		+0.1875	154	419			28	78
65/69		+0.3125	220	465			68	145
70/74		+0.4375	276	350			120	153
75/79	+0.125	+0.5625	272	200	34	25	153	112
80/84	+0.375	+0.6875	232	66	87	24	159	45
85/89	+0.625	+0.8125	141	15	88	9	114	12
90/94	+0.875	+0.9375	58	0	50	0	54	0
95/99	+1.125	+1.0625	10	0	11	0	10	0
100/104	+1.375	+1.1875	0	0	0	0	0	0
TOTAL IN 55°-75° BIN			767	1551	-	-	225	396
TOTAL IN 75°-99° BIN			703	281	271	59	492	170
TOTAL IN 55°-99° BIN			1470	1832	-	-	717	566
TOTAL 24 HR BASIS			3302		330		1284	

TABLE APP3C-5 REDISTRIBUTION OF HEATING SEASON HOURLY OCCURRENCES -O'HARE

TEMPERATURE RANGE (°F)	NOV		DEC		JAN		FEB		MAR		APR		TOTAL		GRAND TOTAL
	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	9:00 AM 5:30 PM	5:30 PM 9:00 AM	
80/84	0	0	0	0	0	0	0	0	0	0	3	0	3	0	3
75/79	1	0	0	0	0	0	0	0	0	0	12	0	13	0	13
70/74	2	0	0	0	0	0	0	0	1	0	22	4	25	4	29
65/69	11	1	0	0	0	0	0	0	3	0	24	11	38	12	50
60/64	14	8	1	0	0	0	1	0	6	2	23	25	45	35	80
55/59	21	19	4	2	1	1	3	1	12	5	27	29	68	57	125
SUB TOT	49	28	5	2	1	1	4	1	22	7	111	69	192	108	300
50/54	29	27	8	5	3	3	6	3	20	9	41	53	107	100	207
45/49	34	39	13	10	7	4	9	4	28	23	44	65	135	145	280
40/44	43	60	27	24	14	9	24	15	45	22	45	84	198	214	412
35/39	41	72	50	67	44	40	52	48	64	82	35	84	286	393	679
30/34	47	82	71	96	80	96	76	112	63	122	12	49	349	557	906
25/29	26	60	45	73	51	82	41	76	33	71	3	19	199	381	580
20/24	12	31	34	55	34	62	22	44	16	45	1	4	119	241	360
15/19	4	19	19	44	24	47	12	33	7	26	0	1	66	170	236
10/14	2	7	13	25	19	32	9	19	2	12	0	0	45	95	140
5/9	2	1	7	19	13	25	7	14	0	4	0	0	29	63	92
0/4	1	2	4	13	6	22	7	14	0	1	0	0	18	52	70
-5/-1	0	2	2	6	3	13	2	12	0	0	0	0	7	33	40
-10/-6	0	0	0	4	1	5	0	6	0	0	0	0	1	15	16
-15/-11	0	0	0	2	0	3	0	1	0	0	0	0	0	6	6
-20/-16	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
SUB TOT	241	402	293	444	299	443	267	401	278	417	181	359	1559	2466	4025
GRAND TOTAL	290	430	298	446	300	444	271	402	300	424	292	428	1751	2574	4325

TABLE APP3C-6

DERIVATION OF EQUIVALENT FULL LOAD HEATING HOURS (EFL_h)
FOR ROOM TEMPERATURES AT
75° F AND 55° F AND (-5° F) DESIGN TEMPERATURE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
OUTDOOR TEMP RANGE °F	DECIMAL % OF FULL LOAD AT MIDPOINT		HOURLY OCCURRENCES		BTU/YR PER BTUH DESIGN LOAD OR EQUIVALENT FL HTG HRS/YR			
					ROOM 75° F		ROOM 55°F	
	ROOM 75°F	ROOM 55°F	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM	9:00AM 5:30PM	5:30PM 9:00AM
70/75	.031		61	25	1	1	0	0
65/69	.094		82	54	7	5	0	0
60/64	.156		91	86	14	13	0	0
55/59	.219		117	129	25	28	0	0
50/54	.281	.031	159	185	44	51	4	5
45/49	.344	.094	166	240	57	82	15	22
40/44	.406	.156	213	275	86	111	33	42
35/39	.469	.219	294	427	137	200	64	93
30/34	.531	.281	349	571	185	303	98	160
25/29	.594	.344	199	384	118	228	68	132
20/24	.656	.406	119	241	78	158	48	97
15/19	.719	.469	66	170	47	122	30	79
10/14	.781	.531	45	95	35	74	23	50
5/9	.844	.594	29	63	24	53	17	37
0/4	.912	.656	18	52	16	47	11	34
-5/-1	.969	.719	7	33	6	31	5	23
-10/-6	.1031	.781	1	15	1	15	1	11
-15/-11	.1094	.844	0	6	0	6	0	5
-20/-16	.1156	.906	0	1	0	1	0	1
TOTAL BELOW 75° F			2016	3052	888	1535	-	-
TOTAL BELOW 55° F			1665	2758	-	-	422	778

TABLE APP 3C-7 REDISTRIBUTION AND SUMMARY OF MEAN COINCIDENT WET BULB TEMPERATURE OCCURENCES FOR EACH DRY BULB TEMPERATURE BIN

wbt	DRY BULB TEMPERATURE (dbt) °F																						TOTALS			
	99/95		94/90		89/85		84/80		79/75		74/70		59/65		64/60		59/55		54/50		49/45		55°dbt		75°dbt	
°F	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:30 to 9:00	9:00 to 5:30	5:00 to 9:00
79	3																						3	0	3	0
78	2																						2	0	2	0
77																							0	0	0	0
76			17																				17	1	17	1
75			14																				14	1	14	1
74	3		19																				22	0	22	0
73	2				113	20																	115	20	115	20
72			5		1																		6	0	6	0
71			1				128	45															129	45	129	45
70					12		47	22															59	22	59	22
69					10				65	80													75	80	75	80
68							21	3	124	101													145	104	145	104
67							33	4															33	4	33	4
66											106	215											106	215	0	0
65									38	12	49	78											87	90	38	12
64							3		47	12													50	12	50	12
63									11	1			58	244									69	245	11	1
62											55	32											55	32	0	0
61											64	37	37	83									101	120	0	0
60											20	6	64	68									84	74	0	0
59											3		77	76	26	152							104	228	0	0
58													10	2	24	81							34	83	0	0
57															45	100							45	100	0	0
56													27	11	14	9							41	20	0	0
55															82	94	9	69					91	163	0	0
54															23	25	21	56					44	81	0	0
53															5	3							5	3	0	0
52																	47	101					47	101	0	0
51																	88	132	1	8			88	132	0	0
50																	38	35	4	21			38	35	0	0
49																			23	105			0	0	0	0
48																			12	10			0	0	0	0
47																			120	183			0	0	0	0
46																			60	63		4	0	0	0	0
45																					14	66	0	0	0	0
44																							0	0	0	0
43																					152	295	0	0	0	0
42																					27	24	0	0	0	0
TOTALS 65°wbt	10	0	56	0	136	20	229	74	189	181	106	215	0	0	0	0	0	0	0	0	0	0				
55°wbt	10	0	56	0	136	20	232	74	285	206	297	368	273	484	109	342	0	0	0	0	0	0				

TABLE APP3C-8

DERIVATION OF EQUIVALENT FULL LOAD VENTILATION HRS (EFL_V) FOR COOLING LOADS AT ROOM CONDITION OF 75°db/61.6wb

Wbt °F	h@Wbt Btu/lb air	h to RM RM h=27.52 @75db/ 61.6wb	%Full Load	HOURLY OCCURRENCE Above 75°dbt 9-5:30	5:30-9	EQUIVALENT FULL LOAD VENTILATION HRS/YR 9-5:30	5:30-9	TOTAL
79	42.51	14.99	136	3	0	4	0	4
78	41.47	13.95	127	2	0	2	0	3
77	40.46	12.94	118	0	0	0	0	0
76	39.47	11.95	109	17	1	18	1	20
75	38.51	10.99	100	14	1	14	1	15
74	37.57	10.05	91	22	0	10	0	20
73	36.64	9.12	83	115	20	95	16	112
72	35.75	8.23	75	6	0	4	0	4
71	34.87	7.35	67	129	45	86	30	116
70	34.01	6.49	59	59	22	34	12	48
69	33.17	5.65	51	75	80	38	40	79
68	32.35	4.83	44	145	104	63	45	110
67	31.55	4.03	37	33	4	12	1	14
66	30.77	3.25	30	0	0	0	0	0
65	30.00	2.48	23	38	12	8	2	11
64	29.25	1.73	16	50	12	8	1	10
63	28.52	1.00	9	11	1	1	0	1
62	27.80	0.28	3	-	-	-	-	-
61	27.10		-4	-	-	-	-	-
60	26.41			-	-	-	-	-
59	25.74			-	-	-	-	-
58	25.08			-	-	-	-	-
57	24.43			-	-	-	-	-
56	23.80			-	-	-	-	-
55	23.18			-	-	-	-	-
54	22.58			-	-	-	-	-
53	21.98			-	-	-	-	-
52	20.83			-	-	-	-	-
51	20.83			-	-	-	-	-
50	20.27			-	-	-	-	-
49	19.72			-	-	-	-	-
48	19.18			-	-	-	-	-
47	18.65			-	-	-	-	-
46	18.13			-	-	-	-	-
45	17.62			-	-	-	-	-
44	17.12			-	-	-	-	-
43	16.63			-	-	-	-	-
42	16.15			-	-	-	-	-
TOTAL	-	-	-	719	302	412	155	567

D. DEVELOPLMENT OF ACTUAL BUILDING ENERGY INDICES (EI_b)

This paragraph contains guidelines for filling out of Forms 3-3, the most important and complex of the Building Energy Appraisal Forms. Forms 3-2 and 3-4 can be filled out in a similar fashion.

The following considerations apply:

1. The air handling systems are a major energy consumer in most ERDA laboratory/office type buildings. Therefore, as much information on this system as possible should be gathered during the building survey. For all-air HVAC systems, early completion of Form 4-1, page 15 is recommended.

2. In the guidelines below, it was assumed that Form 4-1, page 15 was filled out with actual HVAC equipment related data prior to completion of Form 3-3.

3. For exemplification purposes, energy data for a typical laboratory office type building (Building 212 Materials Science at Argonne National Laboratory ANL-East) were used to fill out Form 3-3. The filled out Forms have been enclosed at the end of this Appendix.

4. The EFL hours developed under paragraph C. above are considered applicable.

D.1. Net Actual Building Cooling Output (Form 3-3, pg.1)

D.1.1 Building Cooling Areas. Tables showing building exposed areas (vertical and roof) should be developed. Total areas for each exposure should be indicated.

Tables showing interior areas (floor and partitions) should also be developed. Separate totals should be indicated for cooling and non-cooling areas.

When complex buildings are analyzed, subtotals by wings or other subdivision may be helpful.

D.1.2 Transmission Index (EI_t)

a. EFL Hours are extracted from Table APP 3B-7. Col. (6) + (7) for the 24 hr total and 95° - 68° temperature difference (for full load with 68° F room).

b. Col.(4) = Col. (1) x (2) x (3)

c. Col.(5) = Col. (4)/SF_c

d. Col.(7) = Col. (5) x Col. (6)

D.1.3 Solar Index (EI_s)

a. Solar load from the guidelines in BEH Par. 3B5.2a is taken as 1 x the Btuh/SF for total transmission, Col. (5).

b. EFL hours are taken as 40% of those for transmission in view of average sunlight periods of 12 hrs/day and allowance for cloud cover.

c. In view of the large load from once-through ventilation in laboratory/office type buildings, these approximations will not create substantial error in overall building load and energy consumption.

D.1.4 Occupancy Index (EI_o)

a. Coincident occupancy for cooled areas is the total building occupancy of 300 prorated over the areas served by active HVAC and H & V units or, from Form 4-1, Pg. 15, Col.(3) and (5)

$$(135{,}900/238{,}700)\ 300 = 178 \text{ occ}$$

b. The EFL hours of occupancy is derived by analysis of a typical week broken up into typical Monday to Friday (M-F); Saturday, Sunday and Holiday (S-S-H); and pertinent occupancy periods. With essentially continuous 24 hr operation, distribution of the assumed percentage of occupancy is applied to the cooling operating hours between 52° and 99° F dbt outdoors from Table App 3B-7 in the daily time slots of Col (4) and (5), as follows:

M-F, 8 AM-5 PM:	
(1729 occurrences)(45/63 hrs per wk)(95%) =	1173
5 PM-8 AM: (2159)(75/105)(5%) =	77
S-S-H, 8 AM-5 PM: (1729)(18/63)(10%) =	49
5 PM-8 AM: (2159)(30/105)(2%) =	12
Total EFL Occupancy Hours	1311

D.1.5 Lighting and Receptacle Index (EI_{lr})

a. The total building lighting load is estimated to be 266 kw and the reconciliation of this with total demand is synthesized in Form 3-4, Pg 5, where the actual estimated coincident demand of 1826 is reconciled with the annual consumption of 10,130,000 kwh.

b. The breakdown of lighting load and usage is given in Table APP3D-1, with load profiles, area breakdowns and a reconciliation with the building total of 266 kw.

TABLE APP3D-1 BUILDING LIGHTING & RECEPTACLE DISTRIBUTION

AREA TYPE	GROSS SQ.FT.	LIGHTING W/SF	LIGHTING DKW	MON-FRI % DKW 8 Hrs	MON-FRI % DKW 9 Hrs	MON-FRI % DKW 7 Hrs	S-S-H % DKW 8 Hrs	S-S-H % DKW 5 Hrs	S-S-H % DKW 11 Hrs
HVAC	135,945	1.3	177.0	30%	100%	50%	30%	30	30%
H & V	102,755	.8	82.0	30	100	50	30	30	30
Secured	28,737	.1	2.7	30	100	50	30	30	30
Vent only (covered by above units)									
Loft	17,458	.2	3.5	30	30	30	30	30	30
Tunnels	10,860	.1	1.1	20	20	20	20	20	20
Other	5,283	-	-	-	-	-	-	-	-
	301,038	0.88	266.0						

c. By weighing the above HVAC lighting profile over a typical week the annual EFL hours become 4622, which is somewhat higher than the EFL hours for the total building lighting in Form 3-4, Pg 5. This is reasonable in view of the type of increased usage for HVAC and H & V areas.

d. The cooling EFL hours is proportioned to the annual EFL hours on the basis of annual cooling operating hours between 52^{o} and 99^{o} F dbt outdoors for ANL,

EFL_c = (3888/8760)4622 = 2051 hours

D.1.6. <u>Internal Process SH Index</u> (EI_{ps})

a. Process loads chargeable to cooled areas are assumed as 85% of the total bldg. process load from Form 3-4, Pg 5, since most of the process equipment is in such spaces or (.85x257) = 222kw.

b. The 2190 EFL hours from Form 3-4 is based upon a high diversity, with light annual load factor. The EFL_c for cooling season operation is 2190x(3888/8760) = 972

c. With reference to note 3 of Form 3-3, Pg 2, it is assumed that 25% of the refrigeration energy from the demineralized water chiller directly cools some of the electric process loads. Since Form 3-4, Pg 5 shows 300,000 kwh annual input to this chiller = 300,000 T-hrs, the net process load then becomes:

Gross Heat Gain
= 222x3413x972 EFL_c hours = 730,000,000 Btu/yr

Cooling Credit
= 0.25 (300,000 T-hrs)12,000$\frac{3888}{8760}$ = (<u>390,000,000</u>)

340,000,000 Btu/yr

EI_{ps} = 340,000,000/135,945 = 2491 Btu/SF/yr

Net Process Electric Load
= 222-(390,000,000/3413) = 111 kw
= 111 kw x 3,413 = 389,000 Btuh = 2.86 Btu/SF

and EFL_c = 2491/2.86 = 871

d. All "General Building Services" (E_b) are assumed to be in non-cooled areas.

D.1.7. Actual SA/RA Fan Index (EI_f)

a. Exhaust fans may be assumed to contribute no heat to the cooling load, if they are located in the loft and their energy is vented.

b. "Comfort HVAC Fans" (E_{fhc}) or 350 kw from Form 3-4 Pg 5 represents all supply fans in the building, made up of the following fans from Form 4-1, Pg 15 (active fans, only):

	MHP	KWD
HVAC (cooling system)	398	293
H & V(heating only	130	50
Vent (no htg. or cooling)	10	7
	538	350

c. This low part load relationship of kw and MHP reconciles well with the nameplate vs. running amp analysis summarized for these groups in Col. 31 & 32 of Form 4-1, Pg 15. The 538 MHP, corresponding to approximately 490 Full Load kw, yields an operating load factor of 350/490 = 71% while the actual running amp ratio to Full Load amps is 60%. The cooling gain from fan motors is taken as 88% of the KWD to allow for motor inefficiency losses which are not within the air stream or 257 kw.

d. These fans run 8760 hrs/yr, therefore the EFL_c hours is identical to the total cooling season operating hours or 3888 hours.

D.1.8. Ventilation Index (EI_v)

a. The OA CFM for all the HVAC (cooling) systems combined is 154,697 from Col(8) and (10) of Form 4-1, Pg. 15. This includes the minimum OA load for all the once-through and recirculating HVAC units which are active.

b. The EFL_c hours for ventilation SH is obtained from Table App 3B-7, as the sum of Col(6) and (7) for the 99^o to 68^o F bins during which time the ventilation air imposes a SH gain on the system.

c. An adjustment to ventilation LH load indicated on Pg 1 is only required when the room humidity resulting from the actual coil LAT is above or below the assumed design conditions for the room. In this example, the assumed de-

sign condition of 68 dbt/55% RH/51 dpt (refer to Fig. App. 3B-1) would actually be attained from the design coil LAT. (It is noted, however, that if a higher room design condition were assumed (e.g. 75 dbt/50% RH/57 dpt, noted as room condition 3) that it could not be attained with the same 52° coil leaving air temperature. Instead the much lower room dpt of 51°F would result, regardless of "assumed" room condition and if the calculation were not adjusted to reflect this differential between the room condition actually attained (51 dpt) and that assumed (57 dpt) then the calculated refrigeration load would be considerably short of the requirements).

D.1.9. Reconciliation of Supply Air & Tons of Refrigeration (T.R.). For this analysis, inspection of operating records showed disagreements with these results as follows:

- calculated vs. in-service A/C tons
- peak steam meter reading vs. total A/C tons
- calculated air quantities vs. actual
- unsatisfied room thermostatic settings

Page 1A was prepared to simulate actual maintained room temperature and actual air quantities. The A/C tons and peak steam flow could not be reconciled without further investigation. Despite this, page 1A is more representative of actual building conditions and is used in lieu of page 1.

D.2 Gross Peak Output Cooling Load (Par 1b)

D2.1 Penalty Load. The net load and annual energy indices in Par. 1a represent bar building requirements exclusive of the penalty loads associated with the various system types. In Building 212 the hot deck reheat of dual duct systems imposes a 25 F degree lift on the 55° F fan LAT to provide the 80° F hot duct supply temperature at peak load. Given the condition of spillover of hot air into the cold stream (as reported in ECO HA-3), in addition to the minimum warm port leakage when all of them are shut (trying to maintain 68° F room), an average condition of 8 F degree SA temperature rise based upon field reports, and 2% hot port leakage may be assumed. Dual duct SA totals 77,700 CFM. Therefore,

Leakage penalty = 1.08 (77,700 x 0.02) (80° - 72°) =	671,300 Btuh
Spillover penalty = 1.08 x 77,700 (8° rise) =	671,300 Btuh
Total penalty = 112 T.R. =	1,342,600 Btuh

D.2.2. Supplementary Heat Gains

Besides the system penalties, there are supplementary loads on refrigeration from pump energy, transmission gains to chilled water piping and ductwork, as well as duct leakage. These are estimated at 10% or 118 tons because of the extensive runs and casings in unconditioned areas.

D.2.3 Gross Output

The resulting gross output of 1,412 tons is 243 tons less than the 1655 tons of capacity in service at full load, or 15% lower. Building staff indicated that the refrigeration equipment was somewhat shy of rated capacity, therefore this calculated figure reconciles with operator experience.

D.3 Gross Cooling Output Load and Energy Reconciliation (Par le).

D.3.1 Load Reconciliation

The coincident peak loads in Col. (4) of Par. le must be reconciled with the rated capacities of all refrigeration equipment in service, by totaling to the estimated 1412 tons. These peaks must in turn reconcile with any metered or field estimated loads at the annual peak operating periods. The 1377 tons of steam absorption refrigeration load would require 26,438 lb/hr of steam without any allowance for service hot water. There is a discrepancy between this figure and survey data. Consideration of other factors appears to justify the conclusion of 1377 tons rather than 1000 tons. This assumes steam load plus the service water load of 150 lb/hr is reconciled with the 26,588 lb/hr shown in Form 3-4 Pg. 6 Col. (3), as the annual peak load occurring during the cooling season. (This ignores the load spikes which occur when the steam turbogenerators are tested). Similarly, the electric refrigeration load of 35 tons = 35 kw is reconciled in Form 3-4 Pg. 5 for E_{rc} in Col. (3).

D.3.2 Energy Reconciliation

The impact of the penalty refrigeration loads and supplementary heat gains on annual energy consumption must be estimated before the calculated T-hrs can be reconciled with overall metered steam consumption for the building in Form 3-4, Pg. 7; item S_{rc}.

a. Summer Reheat:

This can be approximated because all the HVAC systems employ artificial heat during cooling periods to replace the portion of the internal sensible heat load which disappears at part load conditions. This cumulative difference is the annual difference between the net internal SH cooling requirement (i.e. 42,762 Btu/SF/yr from Form 3-3, Pg 1A) and the annual internal SH energy available from the supply air off the cooling coil in its rise from 52° F to 72° F. The annual coil SH energy is the sum of the ventilation air SH and the available internal SH energy. It is a function of the EFL_c hours for the full building load represented by cooling the total air from its average mixture temperature of 92.7° F to 52° F. The building average mixture temperature is the hypothetical blend of 154,697 CFM of outside air (for the once-through and the recirculating units) with the return air to the recirculating units; as if all units were combined into one air handler. Thus:

Mix temperature on coil	
= 72°F + (154,697/172,000)72 = 92.7° F	
Total cooling coil annual SH energy	
from Table App 3B-7, Col (8)+(9)	
= 1.08(172,000)(92.7-52)1687 EFL_c hrs	= 12,754x10^6 Btu/yr
Less ventilation annual SH energy	
from Form 3-3, Pg 1A, EI_{vs}	
= (18,853 Btu/SF/yr)135,945 SF	= (2,563x10^6)
Annual available coil SH energy	10,191x10^6 Btu/yr
Less annual net internal SH requirement,	
Form 3-3, Pg 1A	
=(42,762 Btu/SF/yr)135,945 SF	= (5,813x10^6)
Total cooling season reheat energy	4,378x10^6 Btu/yr

b. Hot Port Leakage:

If the hot port of each mixing box is assumed closed (full cooling load) during 20% of the cooling season, leaking 2% of average 100° F warm duct air then the annual leakage penalty is

1.08(0.02x77,700 CFM)(100°-68°)(0.2x3888 hrs) = 38x10^{6}Btu/yr

c. Warm Air Spillover:

On the basis of spillover occurring for a total of 200 hrs. when the outdoor temperature exceeds 88° F, then

the annual spillover penalty from Par D.2.1. is

(671,300 Btu/hr) 200 hrs = 134×10^6 Btu/yr

d. Excess Radiation During 52° to 65° F Outdoor Temperatures:

As a result of fixed hot water radiation scheduling and difficult-to-control steam radiation, it is assumed that 30% excess radiation input is experienced during the 223 EFL_h heating season when refrigeration is still in use. The annual radiation penalty from this, using the total transmission loss from Form 3-3, Pg 5 as a base is

$$(4{,}075{,}000 \text{ Btu/hr})(223 \text{ EFL}_h)0.3$$
$$= (908 \times 10^6)0.3 = 273 \times 10^6 \text{ Btu/yr}$$

e. The sum of these penalties, totals $4{,}823 \times 10^6$ Btu/yr and represents unnecessary steam energy consumption, as well as a corresponding refrigeration energy consumption equal to

$$(4{,}823 \times 10^6 \text{ Btu output}) \times \frac{(19.3 \times 1019 \text{ Btu input})}{(12{,}000 \text{ Btu output})}$$
$$= 4{,}823 \times 10^6 \times (19{,}667/12{,}000) = 7{,}904 \times 10^6 \text{ Btu/yr}$$

f. The supplementary heat gains to the air and water streams, plus duct leakage may be taken at 5% of the refrigeration steam input, and the gross annual absorption refrigeration is:

Total net refrigeration output (Pg 1A)	= 1,512,000 T-hrs
Less electric refrigeration output (Pg 3, Col 7)	= 210,000
Steam refrigeration output	1,302,000 T-hrs
Equivalent net steam input @19,667 Btu/T-hr	= $25{,}605 \times 10^6$ Btu
Plus penalties from Par D.3.2.e	+ $7{,}904 \times 10^6$
	$33{,}509 \times 10^6$
Supplementary heat gains = $(33{,}509 \times 10^6)(.05) = 1{,}676 \times 10^6$ output	
Equivalent refrigeration input @19,667/12,000	= $2{,}745 \times 10^6$
Gross absorption refrigeration input Energy	= $36{,}254 \times 10^6$ Btu

g. The equivalent T-hrs output for this gross input of steam is

$$(36{,}254\text{x}10^6 \text{ Btu})/(19{,}667 \text{ Btu/T-hr}) = 1{,}843{,}392$$

which may be entered in Form 3-3 Pg 3 as the bracketed sum of the absorption units in Col (7), for a preliminary reconciliation with other survey data on the refrigeration units which may be known (i.e. metering data on steam to each refrigeration unit.) If this were the case, then the total annual energy could then be distributed among the various refrigeration units in Pg 3 based upon a reasonable load factor for each (not available from operating personnel) and the estimated operating hours (see note 2).

In this case, lacking such metered data, completion of this page may be left until the prorated steam system losses described in the final reconciliation of Par D6.4.b are made.

D.4. Building Cooling Energy Indices (Par 1.f.)

The T-hr figures from Pg 3 are entered in Col (2) of Pg 4 and extensions made based on the indicated conversions.

D.5. Net Actual Building Heating Output (Par 2.a.)

Similarly to the development of cooling output, the areas are obtained from tables referenced under D.1.1. above, and the EFL_h hours from Appendix Table 3B-8, on the basis of the entire building being heated to 68° F. The ventilation air is the sum of Col. (8) to (11) in Form 4-1, Pg. 15.

D.5.1. Heating Energy Credits, Col (8)

All the internal energy in the HVAC and H&V areas generated annually from lights, occupancy, process and fans is considered a credit to building heating requirements, in the ideal case when ventilation air is heated only to 52° F and booster coils, radiation and internally generated heat warms it up to room temperature, without excess radiation booster coil or warm duct heating. These theoretical electrical energy credits from Form 3-4, Pg 5 are prorated to the annual heating hours of operation from Appendix Table 3B-8. Such credits are applied to the areas which are ventilated with tempered air supply:

Lights (Table APP 3D-1)
177+82 = 259 kw in HVAC and H&V areas
(259/266)(1,182,000 kwh/yr)(3,413)(5874/8760)
$= 2,634 \times 10^6$ Btu

Process: Area = 135,900 + 102,800 = 238,700 SF
(238,700/301,000)(563,000 kwh/yr)(3,413)(5874/8760)
$= 1,021 \times 10^6$

Fans: (3,066,000 kwh/yr)(3,413)(5874/8760)
$= 7,017 \times 10^6$

Occupancy: (applying the occupancy EFL_c hrs ratio to heating operating hours)
=(300x220 Btuh)(1311/3888)5874 = 313×10^6

Solar Credit: (based upon applying 70% of the summer solar gain from Par 1a to the HVAC and H&V areas and extrapolating it in the ratio of heating/cooling operating hours.)
= (1264 Btu/SF/yr)(238,700 SF)(5874/3888)(0.7)
$= 319 \times 10^6$

Total Theoretical Energy Credit:
enter in Col (8), Par 2a $11,122 \times 10^6$ Btu

D.5.2. <u>Heating Load Credits</u>, Col (5)

a. The above credits are substantial for annual energy consumption reduction because they react on a 24 hour basis. The winter peak load, however, with 24 hour once-through air systems, occurs at night when solar gains are zero and many of the internal heat gains are small. With an approximate 10 F deg. temperature range between day and night, the load at night would be in a ratio of night/day T.D. of 72/62, or 16% greater during unoccupied periods, when credits can be estimated as follows:

Lights: 259 kw x(35% from Table APP 3D-1) 3,413
= 376,000 Btuh

Process:
257 kw (238,700/301,000)(10%) 3,413
= 70,000

Fans: 350 kw x 3,413 (full load 24 hrs/day)
= 1,190,000

Occupancy: 300x5%x220 = 3,000

Total heating load credit; enter Col(5) = 1,639,000 Btuh

b. Since this load credit is only 6.5% of the 25,568,000 Btuh total heating output then night load still governs with the credit taken.

D.6. Gross Peak Output Heating Load & Energy Reconciliation

D.6.1. Load Reconciliation.

During the peak load condition, without sun effect or substantial internal loads, and with mostly once-through air supply, there is little tendency for supplementary heating systems such as radiation to be out of control and to create an oversupply of heat. For the same reason, ventilation penalties for once-through systems are not substantial, therefore, the penalites are considered zero for Building 212, in Form 3-3, Pg 6, Par 2b. However, annual energy consumption for the radiation and ventilation heating systems may be substantially in excess of the net building output.

D.6.2 Radiation System Energy Reconciliation

The energy penalties in the radiation system arise from summer and winter excess radiation, and are additive to the transmission component of the net building heating output, since almost all transmission is handled by the radiation system. Below outdoor temperatures of 68° F, radiation which is scheduled to handle transmission losses in shaded perimeter zones tends to oversupply, because its control does not respond to sun or internal heat gains; also, for comfort reasons, the actual schedule is lifted above theoretical transmission loss requirements. Besides the 273×10^6 Btu/yr excess radiation during 52 to 65° F weather, already allowed for in Par D.3.2.d., the same 30% is considered applicable below 52° F weather. From Col 8 of Form 3-3, Pg 5, the remaining winter excess radiation is:

$(9104-273)10^6 \times 0.3$ =	$2,649 \times 10^6$ Btu/yr
Summer excess	273×10^6
Net annual radiation requirement	$9,104 \times 10^6$
Gross radiation input energy	$12,026 \times 10^6$ Btu/yr

D.6.3. Ventilation System Energy Reconciliation (Par 2a, Col 8)

a. Ventilation energy penalties arise from the reheat, hot port leakage and warm air spillover described under refrigeration in Par D.3.2; as well as from other ventilation system characteristics which are not considered substantial with predominantly once-through systems.

b. Net ventilation energy is determined from Form 3-3, Pg 5 by allocating all annual energy credits to ventilation, since these internal and solar loads evaluated in Par D.5.1 all contribute to a reduction of main heating coil, hot deck or booster coil heating energy input. Thus, from Col (8)

Gross ventilation energy =	$48{,}016 \times 10^6$ Btu/yr
Credits =	$(11{,}122 \times 10^6)$
Net ventilation heating energy =	$36{,}894 \times 10^6$ Btu/yr

c. Ventilation penalties from Par D.3.2 (without excess radiation = $(4823 - 273) \times 10^6$ = $4{,}550 \times 10^6$

Gross ventilation input energy =	$41{,}444 \times 10^6$ Btu/yr

D.6.4. Distribution System Losses and Unaccounted for Consumption

a. The steam distribution system losses in Building 212 with the steam system alive 8760 hrs/yr may be assumed at 3% of the annual gross steam consumption input calculated. To estimate this, the tabulation below summarizes all the previously calculated consumption figures, as well as the one for Service Hot Water in Form 3-3, Pg 8. The losses are taken for this total and the result is reconciled with the total actual steam consumption in Form 3-4, Pg 7, Col (8). Any unaccounted for consumption plus distribution losses, are then distributed proportionally among the various steam system energy components:

b. Steam Reconciliation Tabulation:

SOURCE PAR	ENERGY COMPONENT	ANNUAL ENERGY INPUT - 10^6BTU CALCULATED	DISTRIBUTED	ACTUAL
D.3.2.f	Refrigeration, S_{rc}	36,254	1,983	38,237
D.6.3.b	Ventilation Air Handlers, S_{ac}	41,444	2,267	43,711
D.6.2	Radiation, S_{rod}	12,026	658	12,684
	Service H.W., S_{dhw}	612	34	646
	Total (without losses)	90,336		-
	Distribution Losses @ 3%	2,710	= 4,942	-
	Unaccounted for 2.3%	2,232		
		95,278		95,278

c. The figures in the last column may now be entered in Form 3-4, Pg 7, representing a calculated reconciliation with only 2.3% unaccounted for steam consumption.

d. After the reconciliation, the final input and corresponding output energy figures may be finalized in Form 3-3, Pgs 3, 4 and 7.

FACILITY: BUILDING

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

FORM 3-3
PAGE 1 OF 11
DATE:
BY

1. ACTUAL BUILDING SPACE COOLING (For Comfort or Process) (5) EI_c

a. Net Actual Building Cooling Output: Area = 135,945 SF_c; Summer Design — Inside: 68°dbt/55%/51°dpt; Outside: 95°dbt/78°wbt

	(1) AREA SF	(2) TRANSMISSION BTUH/SF/°F	(3) °F-TEMP DIFFER	(4) LOAD-BTUH	(5) BTUH/SF_c	(6) EFL_c HRS/YR	(7) REFRIG OUTPUT BTU/SF_c/YR	
(1) Skin Transmission								
Net Wall SF_w	47,942	0.25	27	324,000	2.380	783	1,864	$=EI_w$
Glass SF_g	9,444	1.13	27	288,000	2.118	783	1,658	$=EI_g$
Roof SF_r	77,845	0.10	27	210,000	1.545	783	1,210	$=EI_r$
Interior Walls SF_i	50,540	0.31	17	266,000	1.957	783	1,532	$=EI_i$
Total Transmission	—	—	—	1,088,000	8.003	783	6,266	$=EI_t$
Solar Gain: TAKE AS =	TRANSMISSION GAIN	@ 40% EFL HRS		1,088,000	8.003	313	2,505	$=EI_s$
Actual Occupancy SH = 178 x 220 Btu/Occ				39,000	0.288	1,311	378	$=EI_{os}$
Actual Lighting & Receptacles 177 kw x 3,413 Btu/kw				604,000	4.444	2,051	9,115	$=EI_{lr}$
(3) Internal Process SH Loads (NET 130 - 16 = 114 kw)				389,000	2.860	871	2,491	$=EI_{ps}$
Subtotal (Transmission, solar, occupancy, lighting & process)				3,208,000	23.598	—	20,752	
(2) Actual Fan SH Loads (Supply & Return) 257 kw x 3,413 Btu/kw				877,000	6.45	3,888	25,085	$=EI_f$
Internal SH				4,086,000	30.049	1,525	45,837	
Actual Occupancy LH 178 x 180 Btu/Occ				32,000	0.236	1,311	309	$=EI_{ol}$
Process LH Loads				—	—	—	—	$=EI_{pl}$
Internal TH				4,118,000	30.285	—	46,146	
(1) Vent SH = 1.08 (154,697 CFM) (95 - 68) ΔF°				4,511,000	33.182	783	25,9[illegible]2	$=EI_{vs}$
Vent LH = 4840 (154,697 CFM) (.0168 - .008) ΔW				6,588,500	48.467	1,476	71,537	$=EI_{vl}$
Adjustment to Vent LH for Δ (Rm W attained and Design Rm W) =Vent LH = 4840 (CFM) (-) ΔW				—	—	—	—	$=EI_{vl}$
Net Calculated Cooling Load (Output for Building)				15,217,500	111.934	1,284	143,[illegible]	$=EI_c$
Internal Sensible Heat Factor = Internal SH/Internal TH = 4,086,000/4,118,000 =							[illegible]	$=ISHF$
Required SA CFM = Internal SH/1.08 $(T_r - T_c)$ = 4,086,000/1.08 (68 - 52) =							236,[illegible]00	$=CFM_s$
Actual S.A. CFM (Form 4-1, Pg. 15, Column 6, HVAC Total for cooling units only)							170,751	$=CFM_s$

15,217,500 BTUH LOAD ÷ 1,268 TONS REFRIG   COIL LAT REQ'D @ 0.992 ISHF = 52°dbt/51°wbt

POPE, EVANS AND ROBBINS

FACILITY: BUILDING

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

FORM 3-3
PAGE 1A OF 11
DATE:
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1. ACTUAL BUILDING SPACE COOLING (For Comfort or Process) ⑤ EI_c

a. Net Actual Building Cooling Output: Area = 135,945 SF_c; Alternate Summer Design — Inside: 72°dbt/51°dpt; Outside: 95°dbt/78°wbt

	(1) AREA SF	(2) TRANSMISSION BTUH/SF/°F	(3) °F-TEMP DIFFER	(4) LOAD-BTUH	(5) BTUH/SF_c	(6) EFL_c HRS/YR	(7) REFRIG OUTPUT BTU/SF_c/YR
① Skin Transmission							
Net Wall SF_w	47,942	0.25	23	276,000	2.03	667	1,354 $=EI_w$
Glass SF_g	9,444	1.13	23	245,000	1.81	667	1,201 $=EI_g$
Roof SF_r	77,845	0.10	23	179,000	1.32	667	880 $=EI_r$
Interior Walls SF_i	50,540	0.31	13	204,000	1.50	667	1,000 $=EI_i$
Total Transmission	—	—	—	904,000	6.65	667	4,436 $=EI_t$
Solar Gain: TAKE AS =	TRANSMISSION GAIN	@ 40% EFL HRS		904,000	6.65	190	1,264 $=EI_s$
Actual Occupancy SH = 178 x 220 Btu/Occ				39,000	0.29	1311	375 $=EI_{os}$
Actual Lighting & Receptacles 177 kw x 3,413 Btu/kw				604,000	4.44	2,051	9,115 $=EI_{lr}$
③ Internal Process SH Loads (NET 130-16 = 114 kw)				389,000	2.86	871	2,491 $=EI_{ps}$
Subtotal (Transmission, solar, occupancy, lighting & process)				2,840,000	20.89		17,684
② Actual Fan SH Loads (Supply & Return) 257 kw x 3,413 Btu/kw				877,000	6.45	3,888	25,078 $=EI_f$
Internal SH				3,717,000	27.34	1,564	42,762
Actual Occupancy LH 178 x 180 Btu/Occ				32,000	0.24	1,311	315 $=EI_{ol}$
Process LH Loads				—	—	—	— $=EI_{pl}$
Internal TH				3,749,000	27.58		43,077
① Vent SH = 1.08 (154,697 CFM) (95 - 72) Δ F°				3,842,500	28.266	667	18,853 $=EI_{vs}$
Vent LH = 4840 (154,697 CFM) (.0168 - .008) Δ W				6,588,500	48.467	1,476	71,537 $=EI_{vl}$
Adjustment to Vent LH for Δ (Rm W attained and Design Rm W)							
=Vent LH = 4840 (CFM) (-) Δ W				—	—	—	— $=EI_{vl}$
Net Calculated Cooling Load (Output for Building)				14,180,000	104.310	1,280	133,467 $=EI_c$
Internal Sensible Heat Factor = Internal SH/Internal TH = 3,717,000/3,749,000 =							0.99 =ISHF
Required SA CFM = Internal SH/1.08 (T_r - T_c) = 3,717,000/1.08 (72 - 52) =							172,000 $=CFM_s$
Actual S.A. CFM (Form 4-1, Pg. 15, Column 6, HVAC Total for cooling units only)							170,751 $=CFM_s$

14,180,000 BTUH LOAD = 1,182 TONS REFRIG. COIL LAT REQ'D @ 0.99 ISHF = 52°dbt/51°wbt
ANNUAL NET REFRIGERATION OUTPUT = (133,467 Btu/SF/YR)(135,945 SF) ÷ (12,000 Btu/T-HR) = 1,512,000 T-HRS/YR

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

DATE:
BY:

1. ACTUAL BUILDING SPACE COOLING (Cont'd)
   a. Net Actual Building Cooling Output (Cont'd)

NOTES for Par. 1.a Tabulation

(1) Use actual transmission factors, ΔF, ΔW, design conditions and EFL hrs. as dictated by building process or function.
(2) Include all fan heat which becomes a cooling load.
(3) If any internal SH loads are known to be neutralized by process coolant or refrigeration systems, the net rather than gross process heat gain should be used.
(4) If individual areas have substantially different operating periods for room design conditions, cooling, fan operation or process, etc., or ventilation rates are not constant, or vary in different proportions from air unit to air unit, such load components should be separately calculated and totalized for each component, with pertinent EFL Hrs. for each.
(5) Use separate appraisal forms for distinctly separable process and comfort space cooling systems.

b. Gross Peak Output Cooling Load (Calculated) = Net Output Load (Par.1.a) + Excess or Penalty Loads
   1) Net Calculated Load Output = 14,180,000/12,000 w/o HOT DECK REHEAT AT FULL LOAD = 1,182 Tons (net)
   2) Supplementary Heat Gains @ 10% OF NET CALCULATED LOAD = 118
   3) Penalty Load (6) FROM DUAL DUCT WARM PORT LEAKAGE AND HOT DECK SPILLOVER + 112
   4) Actual Gross Output Load (Calculated) 1,412 Tons (Gross)

NOTES (6) Penalty loads are those in excess of net cooling energy requirements by virtue of system characteristics (e.g. cooling load reheat at system peak for rooms below their individual, non-coincident, peak load). SEE APPENDIX 3, PAR D.2.1

c. Equipment Capacities (Survey Data)
   1) Installed 1760 Tons
   2) In Service 1655 Tons

d. Load Indices:

	Calculated TONS	Installed TONS	~~Estimated or~~ Metered Peak TONS
1) Area Ratio: SF_c/Gross Tons =	135,945/1,412 = 96 SF/T	135,945/1,760 = 77	135,945/1000 = 135
2) SA CFM Ratios: SA CFM/SF_c =	172,077/135,945 = 1.26 CFM/SF	CONSIDERABLE RESERVE	170,751/135,945 = 1.25
SA CFM/Gross Tons =	172,077/1,412 = 120	170,751/1,760 = 97	170,751/1000 = 170

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

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1. ACTUAL BUILDING SPACE COOLING (Cont'd)

e. Gross Cooling Output Load and Energy Reconciliation. (SPACE COOLING ONLY) Estimated or metered breakdown by type of refrigeration input energy. If metered, refer to appropriate form. If not, estimate as follows from field survey or operating hours and load profiles of each type of refrigeration cycle. Reconcile total peak tons with that in Par. 1 b and the appropriate Form 3-4 energy synthesis tabulations.

(1)	(2)	(3)	(4)	(5)	(6)	(7) = (4)×(5)×(6)
REFRIG. UNIT	ENERGY TYPE	CAPACITY-TONS NOMINAL	CAPACITY-TONS PEAK	TOTAL HOURS ② OF OPERATION	LOAD FACTOR	ACTUAL OR ESTIMATED OUTPUT TON-HRS/YR
C-1	ABSORPTION	550	468	3888 x .65 = 2527	0.58	(1,843,392) 681,500
E-1	ABSORPTION	450	382	3888 x .70 = 2721	0.58	SEE APPENDIX 3 598,800
E-2	ABSORPTION	1620T 450	1377T 382	3888 x .70 = 2721	0.58	PAR. D.3.2.g 598,800
F-1	ABSORPTION - 105 T	—	SECURED	- NOT IN	SERVICE	—
G-1	ABSORPTION	170	145	3888 x .20 = 777	0.58	1,944,000 64,900
25T CHILLER						
+ (2)5T UNITS	ELECTRIC	35	35	8760	0.68	@ 1 Ton/Kwh 210,000
TOTALS	Installed	1,760	—			
	In Service	1,655	—			
	Actual Loads ①		1,412	3,888	0.45	2,154,000
	Calculated ①		1,412	3,888	0.45	2,154,000

① Actual and calculated loads are assumed the same, in spite of the steam card readings, since this figure appears to afford a better reconciliation with overall energy use.

② Total hours of operation are derived from cooling hourly occurrences (Appendix Table APP3B-7 = 3888) by applying the seasonal operating factors from the Building Questionnaire Form 2-2 Pg. 2, Par. C.3.

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

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1. ACTUAL BUILDING SPACE COOLING (Cont'd)

f. Building Cooling Energy Indices. (EI_c)

(1)	(2) 1	(3)	(4) 2 3	(5) 2	(6) 2 3	(7) 2
TYPE REFRIGERATION DRIVE	OUTPUT IN TON-HRS/YR	OUTPUT IN PHYS UNITS/YR	BOUNDARY ENERGY INPUT		SOURCE ENERGY INPUT	
			10^6 BTU/YR	BTU/SF_c/YR	10^6 BTU/YR	BTU/SF_c/YR
(1)Steam Turbine Refrigeration Drive		lbs				
(2)Steam or Hot Water Absorption Refrigeration	1,944,000	@19.3 $\frac{LBS}{T\text{-}HR}$ = 37,524 lbs	38,237 @1019 BTU/LB	281,300	62,996 @1679 BTU/LB	463,400
(3)Electric Refrigeration Drive	210,000	4 210,000 kwh	717 @3,413 BTU/KWH	5,280	2,436 @11,600 BTU/KWH	17,900
(4)Gas Turbine Refrigeration Drive		Mcf				
(5)Diesel Engine Refrigeration Drive		Gal				
TOTALS	2,154,000		38,954	286,580	65,432	481,300

NOTES
1. Col (2) taken from total of Table 1_e Col (7)
2. Figures in Col (4) to (7) must reconcile with those in Form 3-4, Pgs 1 to 6
3. Use appropriate conversion factors for Cols (4) and (6)
4. Item (3) Col (3) must equal item c(1) in Par 6 (to avoid duplication of electric energy input in EI_b)

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

FORM: 3-3
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2. ACTUAL BUILDING SPACE HEATING (For Comfort or Process) EI_h

a. Net Actual Building Heating Output: Area = 301,038 SF_h; Winter Design — Inside: 68° dbt; Outside: (-4)° dbt
NO SETBACK; NO HUMIDIFICATION

(1)	(2) AREA SF	(3) TRANSMISSION BTUH/SF/°F	(4) °F-TEMP DIFFER	(5) LOAD-BTUH	(6) BTUH/SF_h	(7) EFL_h HRS/YR	(8) HEATING OUTPUT BTU/YR	(9) HEATING OUTPUT BTU/SF_h/YR
① Skin Transmission	GROSS WALL = 104,689		[68-(-4)]				X 10^6	
Net Wall SF_w	86,016	0.25	72	1,548,000	5.14	2,234	3,458	11,483 = EI_w
Glass SF, Louvres & Doors	18,673	1.13	72	1,519,000	5.05	2,234	3,394	11,282 = EI_g
Roof SF_r	140,010	0.10	72	1,008,000	3.35	2,234	2,252	7,484 = EI_r
Total Transmission				4,075,000	13.54		9,104	30,249 = EI_t
② Vent SH = 1.08 (276,404 CFM) (72) ΔF°				21,493,000	71.40	2,234	48,016	159,508 = EI_{vs}
Total Heating Output				25,568,000	84.94		57,120	189,757
③ Credits From Form 3-4, Pg 5 for electrical items: 259 kw lights								
203 kw process and 350 kw supply air fans; 300 occupants;				(1,639,000)	(5.44)		(11,122)	(36,445)
also solar credit (for energy – not for loads)								
Net Heating Output				23,929,000	79.50	1,922	45,998	152,812 = EI_h

NOTES

① Use actual transmission factors, ΔF, design conditions and EFL hours as dictated by building process or function.

② If individual areas have substantially different operating periods for room design conditions, ventilation quantities or temperature lift, etc., such load components should be separately calculated with pertinent EFL hours and totalized for each load component.

③ Only legitimate credits should be taken, when internal heat gains are determined to be effective in either perimeter areas (with heat losses); in air streams (i.e. heat of light added to return air streams when such captured heat is effectively utilized and not neutralized by outside air mixing or refrigeration); in interior areas when the outside air component of supply air is warmed from the cold supply temperature to room condition; or for other specific system characteristics.

④ Use separate appraisal form for distinctly separable comfort and process space heating systems.

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BUILDING ENERGY SURVEY AND APPRAISAL

ACTUAL BUILDING ENERGY APPRAISAL FORM

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2. ACTUAL BUILDING SPACE HEATING (Cont'd)

b. Gross Peak Output Heating Load
= Net Output Load (Par 2a) + Excess Penalty Loads

1) Net Calculated Output Load	23,929,000	Btuh	23,483	lb/hr
2) Penalty Load ⑤	0		0	
3) Actual Gross Output Load	23,929,000	Btuh	23,483	lb/hr
		@ 1019 BTU/LB		

c. Equipment Capacities:

1) Installed ______

2) In Service ______

d. Load Index — Calculated — Installed — Estimated or Metered Peak

Gross Output/SF_h = ______

NOTE ⑤ Penalty loads are those in excess of net heating energy requirements by virtue of system characteristics (e.g. perimeter radiation scheduled for capacity greater than required to satisfy the transmission loss, when supply air is introduced to the perimeter areas at below room temperature and it is produced from a blend of outside air in excess of the minimum required for cooling).

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ENERGY FLOW DIAGRAM SYNTHESIS

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5. ELECTRICITY
a. For Reconciliation By Energy Systems

(1) CONVERSION DEVICE OR FUNCTION: IDENT	(2) TYPE		(3) COINCIDENT ACTUAL DEMAND KW	(4) HOURS/YR OPER	(5) HOURS/YR EFL	(6) % LOAD FACT	(7) BOUNDARY ENERGY INPUT KWH/YR x 10^3	(8) BOUNDARY ENERGY INPUT 10^6 BTU/YR @ 3,413	(9) BOUNDARY ENERGY INPUT BTU/SF_b/YR	(10) SOURCE ENERGY INPUT 10^6 BTU/YR @11,600	(11) SOURCE ENERGY INPUT BTU/SF_b/YR	(12) CONTINUING ENERGY SYSTEMS
E_{lr}	Ltg-Rec		266	MIX	4442		1,182	4,034	13,400	13,711	45,546	
Erc	Refrig	Comfort	35	3760	3000	.68	210	717	2,382	2,436	8,092	
E_{rp}		Process (Demin)	64	3760	4638	.54	300	1,024	3,400	3,480	11,560	
E_{hc}	Space Htg	Comfort										
E_{hp}		Process										
E_{sc}	Service H.W.	Comfort										
E_{sp}		Process										
	Fans											
E_{fhc}	HVAC S & R	Comfort	350	3760	3760	1.00	3,066	10,464	34,760	35,566	118,145	
E_{fhp}		Process										
E_{feg}	Exhaust	General	291	MIX	5673		1,651	5,635	18,719	19,152	63,620	
E_{fep}		Process	187	3760	3760	1.00	1,638	5,590	18,570	19,000	63,115	
E_{ac}	Auxil.	Cooling	259	3450	3450	1.00	893	3,048	10,125	10,359	34,411	
E_{ah}	For HVAC	Heating	18	5038	5033	1.00	92	314	1,043	1,067	3,544	
E_{ap}	For Process Refrig.		42	3760	3760	1.00	364	1,242	4,126	4,222	14,025	
E_p	Other Process		257	MIX	2190		563	1,922	6,235	6,531	21,635	
E_b	General Bldg. Svce		57	MIX	3000		171	584	1,940	1,984	6,590	
	TOTAL		1,826		5148	1.00	10,130	34,574	114,850	117,508	390,343	

NOTES
1. Use separate sheet for on site power generation and identify accordingly.
2. Col. (3): Projected from equipment connected loads and demand factors, metered, or by reconciliation.
3. Col. (5): Assumed or (7)/(3); Col. (6)=(7)/(3) x (4) or Col. (5)/(4)
4. Col. (7): Col. (3) x (5) or metered. Indicate "M" if metered. Reconcile with Form 3-3 figures.
5. Col. (8) & (10): See SITE ENERGY HANDBOOK FORM E3-3 for Btu Equivalent Conversion Factor.
6. Reconcile total of Col. 7 with annual electrical consumption Form 3-1, Pg. 5.
7. If process and comfort functions are indistinct, show combined figure with bracket. Figure should include all apparatus not in foregoing classifications.

FACILITY: BUILDING:

BUILDING ENERGY SURVEY AND APPRAISAL

ENERGY FLOW DIAGRAM SYNTHESIS

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6. STEAM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CONVERSION DEGRADATION PROCESS		ACTUAL DEMAND LB/HR	HRS/YR		LOAD FACT	BOUNDARY ENERGY INPUT			SOURCE ENERGY INPUT		KEYS TO ENERGY SYSTEM FLOW	
IDENT	TYPE		OPER	EFL		LB/YR	10^6 BTU/YR @ 1019 BTU/LB	BTU/SF_b/YR	10^6 BTU/YR @1679BTU/LB	BTU/SF_b/YR	ORIGIN	CONTINUING
	Power:											
S_{pe}	Electricity											
S_{pd}	Drives											
	Refrig:											
S_{rc}	Comfort		3888			37,524,000	38,237	127,017	63,003	209,286		
S_{rp}	Process											
	Air Handlers:											
S_{ac}	Comfort					42,896,000	43,711	145,200	72,023	239,249		
S_{ap}	Process											
S_{rad}	Radiation (H.W. & STM)					12,447,000	12,684	42,135	20,900	69,426		
	Service Hot Water:											
S_{dhw}	Domestic	50	3760			211,000	215	714	354	1,176		
S_{phw}	Process	100	3760			423,000	431	1,432	710	2,359		
S_{shw}	Space Htg (H.W.)											
S_p	Other Process											
TOTAL		26,533 COINC. PEAK				93,501,000	95,278	316,497	156,990	521,496		

NOTES

1 Cols. (12) & (13): key each line item to originating and continuing forms of energy.
2 Col (3): metered or projected from equipment ratings demand factors or guideline calculations.
3 Col (7): Col (3) x (5) or metered. Reconcile with related figures in Form 3-3 (e.g. $S_{ac} + S_{ap} + S_{rad} + S_{hs}$ must total same as line (3) Form 3-3 Table 2e). Indicate 'M' if metered.
4 Cols (8) & (10): Refer to SITE ENERGY HANDBOOK for Btu conversion factors, or use specific appropriate ones.
5 S_{pe} and S_{pd} include all turbines for electric generation and equipment exclusive of refrigeration.
6 S_{rc} and S_{rp} include all turbine drives for refrigeration.
7 S_{ac} and S_{ap} include all fan-powered HVAC devices (i.e. cooling, heating, H&V, UV, fan-coil, etc.).
8 If turbines are exhausted or extracted, Col (13) should show identification Key to the subsequent energy node (i.e. S_{rp}). Cols (7) to (11) should identify and include these quantities but they should be encircled and not included twice in the totals.

POPE, EVANS AND ROBBINS

Appendix 4

APPENDIX 4

APPENDIX TO CHAPTER 5

This Appendix contains tables, figures and other supporting material for some of the ECOs presented in Chapter 5. See Appendix 5 for references.

TABLE ELM 2-1

SUGGESTED MAXIMUM CAPACITOR RATING WHEN MOTOR* AND CAPACITOR ARE SWITCHED AS UNIT

Induction Motor Horse-Power Rating	Nominal Motor Speed in RPM: 3600		1800		1200		900		720		600	
	Capacitor Rating KVAR	Line Current Reduction %	Capacitor Rating KVAR	Line Current Reduction %	Capacitor Rating KVAR	Line Current Reduction %	Capacitor Rating KVAR	Line Current Reduction %	Capacitor Rating KVAR	Line Current Reduction %	Capacitor Rating KVAR	Line Current Reduction %
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3.5	41
5	2	12	2	13	2	17	3	25	4	32	4.5	37
7½	2.5	11	2.5	12	3	15	4	22	5.5	30	6	34
10	3	10	3	11	3.5	14	5	21	6.5	27	7.5	31
15	4	9	4	10	5	13	6.5	18	8	23	9.5	27
20	5	9	5	10	6.5	12	7.5	16	9	21	12	25
25	6	9	6	10	7.5	11	9	15	11	20	14	23
30	7	8	7	9	9	11	10	14	12	18	16	22
40	9	8	9	9	11	10	12	13	15	16	20	20
50	12	8	11	9	13	10	15	12	19	15	24	19
60	14	8	14	8	15	10	18	11	22	15	27	19
75	17	8	16	8	18	10	21	10	26	14	32.5	18
100	22	8	21	8	25	9	27	10	32.5	13	40	17
125	27	8	26	8	30	9	32.5	10	40	13	47.5	16
150	32.5	8	30	8	35	9	37.5	10	47.5	12	52.5	15
200	40	8	37.5	8	42.5	9	47.5	10	60	12	65	14
250	50	8	45	7	52.5	8	57.5	9	70	11	77.5	13
300	57.5	8	52.5	7	60	8	65	9	80	11	87.5	12
350	65	8	60	7	67.5	8	75	9	87.5	10	95	11
400	70	8	65	6	75	8	85	9	95	10	105	11
450	75	8	67.5	6	80	8	92.5		100	9	110	11
500	77.5	8	72.5	6	82.5	8	97.5	9	107.5	9	115	10

*For use with 3-phase, 60 cycle NEMA Classification B Motors to raise full load power factor to approximately 95%.

Reference: 24

TABLE ELM 2-2

KW MULTIPLIERS TO DETERMINE CAPACITOR KILOVARS REQUIRED FOR POWER-FACTOR CORRECTION

Original Power Factor	Corrected Power Factor 0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.435	1.424	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.075	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.923	0.954	0.980	1.007	1.033	1.060	1.033	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.302	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.519	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.005	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.705	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.645	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.551	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.526	0.654	0.682	0.712	0.743	0.775	0.809	0.845	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.330	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.685	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.705	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.252	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.573	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.155	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.351	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.459	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.031	0.109	0.137	0.167	0.193	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.034	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.053	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.065	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.185	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

Reference: 24

FIGURE HF 1-2

HOW TO DETERMINE HEAT LOSS AND FUEL LOSS

NO. 1 FUEL OIL

On the reverse side are given Tables of *Heat* Losses in the burning of No. 1 Fuel Oil and No. 6 Fuel Oil. From these data *Fuel* losses may be determined with practical accuracy.

Important: In using the tables you will need to know:

1. Percent CO_2 in your flue gas
2. Temperature of flue gas
3. Room temperature

With this information, in hand, proceed as follows: Subtract the room temperature from the flue gas temperature and find this number (approximately) on the scale (top row of figures). Proceed down the scale in the proper column to the line opposite your approximate CO_2 percentage as previously determined (extreme left hand column). The heat loss will be found at the junction of these two lines.

Note: The figures given on the reverse side are based on the fuel analyses given below. This should be taken into consideration when figuring your own heat loss.

Example: Suppose you are burning No. 1 Fuel Oil and your flue gas temperature is 625°F with room temperature at 65°F. The difference is 560°. Find this number on the scale. Suppose your CO_2 was found to be 9%. Proceeding down the "560" column to the CO_2 line of 9%, you will find the figure 24.4. *This* is the percent of *total heat loss* in the flue gas.

How much of this total loss is PREVENTABLE depends upon how high the CO_2 content of the flue gases can be raised and how low the flue gas temperature can be reduced without producing CO or increasing other losses such as carbon (smoke) or ash pit losses.

Carrying on with our example: if, by test or

NO. 6 FUEL OIL

computation, it is determined that the CO_2 can be raised to 14% and the difference between flue gas and room temperatures can be reduced to 460° the total heat loss in the flue gas would be 16.5%. This represents a saving of 7.9% in HEAT.

THE SAVING IN FUEL

The saving in *fuel* is even greater. With a 24.4% loss, 75.6% of the heat is being used while with a 16.5% loss, 83.5% of the heat is being used. The consumption of fuel at the higher efficiency is therefore equal to 75.6 ÷ 83.5 or 90.53% of that used when burned at the lower efficiency. The actual saving in FUEL is therefore 100% – 90.51% or 9.47%. It is, of course, necessary that the rate of steam generation remains constant, that the fuel quality be the same and that no CO be produced or the amount of smoke or ash pit losses increased while obtaining the higher percentage of CO_2.

FOR THE SAME FUELS OF BTU CONTENT OTHER THAN THOSE LISTED

For the same fuels of BTU content other than those listed, use the scale of the fuel which has the nearer BTU value. The errors involved are:

For COAL ± 2% of the calculated fuel saving. **Example:** If the calculated fuel saving is 5%, the actual saving will be between 4.9% and 5.1%.

For OIL ± 5% of the calculated fuel saving.

For NATURAL GASES ± 2% of the calculated fuel saving.

For MANUFACTURED GASES the error may be as great as 20% of the calculated value depending upon the composition of the gas.

FUEL ANALYSES

No. 1 Fuel Oil
(Heat Value 19750 BTU/LB)

	% by weight
C	86.1
H	13.6
O	0.2
N	0.1

No. 6 Fuel Oil
(Heat Value 18150 BTU/LB)

	% by weight
C	89.36
H	9.30
S	0.90
N	0.20
O	0.19
ASH	0.05

REFERENCE 8.

SCALE OF TOTAL HEAT LOSS – FUEL OIL NO. 1

% CO_2	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	24.1	25.8	27.7	29.3	31.3	33.9	34.8	36.4	38.2	40.0	42.9	44.8	45.5	47.0	49.0	50.8	52.4	54.3	56.0	57.9	59.6	61.5	63.5	65.0	66.8	68.8						
3.5	21.7	23.1	24.8	26.2	27.8	29.2	31.7	32.5	33.9	35.3	36.9	38.5	40.0	41.7	43.1	44.8	46.1	47.8	49.4	50.9	52.2	53.9	55.7	57.0	58.3	60.0	63.8	67.8				
4.0	19.9	21.2	22.5	24.9	25.2	26.5	27.9	29.2	31.7	32.0	33.3	35.8	36.0	37.3	38.7	40.0	41.4	42.9	44.1	45.5	46.9	48.1	49.8	50.9	52.1	53.8	57.0	60.2	63.9	67.1		
4.5	18.4	19.7	20.8	22.0	23.2	24.4	25.6	26.9	28.0	29.3	30.4	31.8	32.9	34.2	35.6	36.7	37.8	39.0	40.1	41.2	42.5	43.8	45.0	46.3	47.4	48.8	51.8	54.6	57.8	60.9	63.9	66.9
5.0	17.2	18.5	19.5	20.7	21.7	22.7	23.8	24.9	26.0	27.1	28.2	29.4	30.3	31.5	32.7	33.8	34.9	35.9	36.8	38.0	39.2	40.1	41.7	42.4	43.7	44.7	47.4	50.1	52.9	55.8	58.3	61.2
5.5	16.3	17.4	18.4	19.4	20.4	21.3	22.3	23.3	24.3	25.4	26.3	27.3	28.4	29.4	30.6	31.4	32.4	33.6	34.5	35.3	36.4	37.4	38.4	39.6	40.3	41.7	44.0	46.5	49.0	51.8	54.1	56.5
6.0	15.6	16.5	17.4	18.3	19.3	20.4	21.2	22.0	23.0	23.9	24.9	25.8	26.8	27.7	28.6	29.5	30.4	31.4	32.3	33.1	34.2	35.0	36.0	36.9	37.9	38.9	41.0	43.5	45.8	48.0	50.3	52.8
6.5	14.9	15.7	16.7	17.5	18.4	19.3	20.1	20.9	21.8	22.7	23.6	24.5	25.3	26.1	27.0	27.8	28.8	29.6	30.6	31.3	32.3	33.0	34.1	34.8	35.7	36.5	38.7	40.8	42.9	45.1	47.5	49.7
7.0	14.4	15.3	16.0	16.8	17.8	18.4	19.3	20.1	20.9	21.7	22.4	23.2	24.1	24.9	25.7	26.5	27.3	28.1	28.9	29.8	30.5	31.4	32.3	33.0	33.8	34.6	36.5	38.6	40.5	42.7	44.7	46.6
7.5	13.9	14.6	15.4	16.2	16.9	17.7	18.5	19.2	20.1	20.7	21.3	22.2	23.0	23.8	24.5	25.2	26.0	26.8	27.5	28.2	29.0	29.8	30.6	31.3	32.2	32.9	34.8	36.5	38.5	40.3	42.3	44.2
8.0	13.5	14.3	14.9	15.7	16.3	17.1	17.7	18.5	19.3	20.0	20.7	21.4	22.1	22.8	23.5	24.2	25.0	25.7	26.3	27.0	27.8	28.5	29.2	30.0	30.8	31.5	33.2	35.0	36.8	38.5	40.2	42.1
8.5	13.2	13.8	14.5	15.2	15.8	16.5	17.3	17.8	18.6	19.3	20.0	20.6	21.3	21.9	22.6	23.3	23.9	24.6	25.3	25.9	26.7	27.3	28.0	28.8	29.4	30.1	31.8	33.5	35.2	36.9	38.7	40.2
9.0	12.8	13.4	14.1	14.7	15.4	16.0	16.7	17.3	17.9	18.6	19.3	20.0	20.6	21.2	21.8	22.4	23.1	23.8	24.4	25.0	25.7	26.3	27.0	27.7	28.3	28.9	30.5	32.1	33.8	35.3	37.0	38.5
9.5	12.5	13.2	13.7	14.3	14.9	15.7	16.3	16.8	17.4	18.1	18.6	19.3	19.9	20.5	21.1	21.7	22.4	22.9	23.5	24.1	24.8	25.4	26.0	26.7	27.2	27.9	29.4	31.0	32.5	34.0	35.5	37.2
10	12.3	12.8	13.4	14.0	14.6	15.2	15.7	16.3	16.9	17.5	18.1	18.7	19.3	20.0	20.5	21.0	21.6	22.2	22.8	23.4	24.0	24.6	25.1	25.8	26.3	27.0	28.3	29.9	31.4	32.9	34.4	35.7
11	11.8	12.4	12.8	13.4	13.9	14.5	15.0	15.5	16.2	16.7	17.2	17.8	18.3	18.7	19.4	20.0	20.5	20.9	21.5	22.0	22.6	23.1	23.7	24.2	24.8	25.3	26.7	28.0	29.4	31.8	32.1	33.5
12	11.4	11.8	12.5	12.9	13.4	13.9	14.4	14.9	15.4	15.9	16.4	16.9	17.4	17.9	18.4	18.9	19.5	20.0	20.5	20.9	21.4	22.9	22.4	22.9	23.5	24.0	25.2	26.5	27.8	29.0	30.2	31.7
13	11.2	11.6	12.1	12.5	12.9	13.4	13.9	14.3	14.7	15.3	15.8	16.3	16.7	17.2	17.7	18.1	18.6	19.1	19.6	20.1	20.5	21.1	21.3	21.8	22.3	22.8	24.0	25.2	26.3	27.5	28.8	30.0
14		11.3	11.8	12.2	12.6	13.0	13.4	13.8	14.3	14.8	15.3	15.6	16.2	16.5	16.9	17.4	17.8	18.3	18.7	19.2	19.7	20.2	20.6	21.0	21.4	21.8	22.9	24.1	25.2	26.2	27.4	28.6
15			11.4	11.7	12.4	12.6	13.1	13.5	13.8	14.3	14.8	15.3	15.6	15.9	16.4	16.7	17.3	17.7	18.1	18.4	18.9	19.4	19.8	20.3	20.6	21.0	22.0	23.1	24.2	25.2	26.2	27.3

SCALE OF TOTAL HEAT LOSS – FUEL OIL NO. 6

% CO_2	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	24.5	26.5	28.5	30.2	32.2	34.5	36.5	38.2	40.4	42.2	44.4	46.4	48.2	50.0	52.3	54.3	56.3	58.2	60.3	62.0	64.1	66.2	68.1	70.1								
3.5	21.8	23.4	25.2	26.8	28.6	30.4	32.1	33.8	35.5	37.4	39.0	40.6	42.2	44.0	45.6	47.5	49.2	51.0	52.8	54.0	56.0	57.8	59.9	61.1	63.0	64.9	69.0					
4.0	19.8	21.2	22.8	24.2	25.7	27.3	28.8	30.2	31.6	32.5	34.8	36.3	37.8	39.4	40.8	42.2	43.8	45.1	46.9	48.2	49.8	51.2	52.9	54.2	56.0	57.8	61.1	65.0	68.9			
4.5	18.2	19.4	20.8	22.2	23.5	24.8	26.2	27.4	28.8	30.4	31.5	33.0	34.2	35.4	37.0	38.1	39.4	41.0	42.2	43.5	45.0	46.3	47.9	49.0	50.1	51.9	55.0	58.2	61.8	65.1	68.5	
5.0	16.8	18.0	19.3	20.4	21.7	22.8	23.2	25.3	26.6	27.8	29.0	30.3	31.4	32.6	33.8	35.3	36.2	37.5	38.8	39.8	41.0	42.3	43.8	44.9	46.1	47.5	50.1	53.6	56.3	59.8	62.3	65.8
5.5	15.8	16.8	18.0	19.2	20.3	21.3	22.5	23.5	24.6	25.8	26.9	28.0	29.2	30.2	31.4	32.5	33.5	34.7	35.8	37.0	37.9	39.2	40.1	41.3	42.3	43.8	46.1	49.1	52.0	54.7	57.8	60.1
6.0	14.8	15.8	16.9	18.0	19.0	20.0	21.1	22.0	23.1	24.2	25.2	26.3	27.3	28.2	29.3	30.3	31.3	32.3	33.5	34.3	35.3	36.5	37.5	38.3	39.7	40.5	43.0	45.8	48.2	50.9	53.5	56.0
6.5	14.3	15.2	16.1	17.1	18.0	18.9	19.9	20.8	21.8	22.8	23.7	24.6	25.5	26.5	27.5	28.5	29.4	30.4	31.4	32.3	33.4	34.3	35.1	36.1	37.1	38.0	40.2	42.8	45.1	47.6	49.9	52.1
7.0	13.5	14.4	15.3	16.2	17.1	17.9	18.8	19.7	20.6	21.5	22.4	23.3	24.2	25.0	25.8	26.8	27.7	28.6	29.0	30.2	31.2	32.2	33.0	33.9	34.9	35.8	37.9	40.1	42.1	44.4	46.8	49.0
7.5	13.0	13.8	14.6	15.5	16.3	17.3	18.0	18.8	19.7	20.5	21.4	22.2	22.9	23.7	24.6	25.4	26.3	27.2	27.9	28.8	29.6	30.5	31.2	32.1	33.0	34.9	35.9	37.9	40.0	42.0	44.1	46.1
8.0	12.5	13.3	14.1	14.8	15.7	16.4	17.3	18.0	18.8	19.6	20.4	21.2	21.9	22.7	23.5	24.2	25.0	25.8	26.6	27.4	28.2	29.0	29.9	30.6	31.5	32.1	34.1	36.0	38.0	40.0	41.9	43.9
8.5	12.2	12.8	13.6	14.4	15.1	15.7	16.6	17.3	18.0	18.7	19.6	20.3	21.0	21.6	22.5	23.3	23.9	24.7	25.5	26.2	26.8	27.6	28.2	29.1	29.9	30.8	32.6	34.2	36.2	38.0	39.9	41.8
9.0	11.7	12.4	13.2	13.8	14.6	15.3	15.9	16.6	17.4	18.1	18.8	19.5	20.2	20.8	21.6	22.3	22.9	23.7	24.4	25.0	25.7	26.5	27.1	27.9	28.7	29.4	31.1	32.9	34.6	36.3	38.0	39.9
9.5	11.4	12.1	12.7	13.4	14.1	14.7	15.4	16.0	16.7	17.5	18.1	18.7	19.4	20.0	20.7	21.4	22.1	22.8	23.5	24.0	24.7	25.4	26.1	26.8	27.5	28.1	29.8	31.2	33.2	34.9	36.4	38.1
10	11.2	11.7	12.3	13.0	13.7	14.4	14.8	15.5	16.2	16.8	17.5	18.2	18.7	19.4	20.0	20.6	21.3	21.9	22.6	23.2	23.8	24.5	25.1	25.8	26.4	27.0	28.7	30.1	31.8	33.5	35.0	36.7
11	10.6	11.3	11.8	12.4	12.9	13.5	14.2	14.7	15.3	15.8	16.5	17.0	17.6	18.2	18.8	19.4	20.0	20.6	21.2	21.7	22.3	22.9	23.5	24.1	24.8	25.2	26.8	28.1	29.8	31.2	32.5	34.1
12	10.2	10.7	11.3	11.7	12.3	12.8	13.4	13.8	14.5	15.1	15.6	16.2	16.7	17.2	17.8	18.3	18.8	19.4	19.9	20.4	21.0	21.6	22.1	22.7	23.1	23.8	25.0	26.4	27.9	29.1	30.5	31.9
13		10.3	10.8	11.3	11.8	12.3	12.8	13.3	13.8	14.4	14.8	15.4	15.8	16.3	16.8	17.3	17.9	18.4	18.9	19.3	19.8	20.4	20.9	21.4	21.9	22.4	23.8	24.9	26.2	27.5	28.9	30.0
14		9.8	10.4	10.8	11.4	11.8	12.3	12.8	13.3	13.7	14.3	14.7	15.2	15.6	16.2	16.6	17.1	17.5	18.0	18.5	18.8	19.4	19.9	20.4	20.9	21.2	22.5	23.7	24.9	26.1	27.2	28.5
15			10.2	10.6	11.0	11.4	11.8	12.4	12.7	13.3	13.7	14.2	14.6	15.0	15.4	15.8	16.4	16.8	17.3	17.7	18.2	18.6	19.0	19.5	19.9	20.3	21.5	22.6	23.8	24.9	25.9	27.1
16				10.3	10.7	11.1	11.5	11.8	12.3	12.8	13.3	13.7	14.0	14.4	14.8	15.3	15.7	16.2	16.6	16.9	17.4	17.9	18.2	18.8	19.1	19.5	20.6	21.6	22.7	23.8	24.8	25.9

REFERENCE 8.

FIGURE HF 1-3

FIGURE HF 1-4

HOW TO DETERMINE HEAT LOSS AND FUEL LOSS

NATURAL GAS

On the reverse side are given Tables of *Heat* Losses in the burning of Natural Gas and Producer Gas. From these data *Fuel* losses may be determined with practical accuracy.

Important: In using the tables you will need to know:

1. Percent CO_2 in your flue gas
2. Temperature of flue gas
3. Room temperature

With this information, in hand, proceed as follows: Subtract the room temperature from the flue gas temperature and find this number (approximately) on the scale (top row of figures). Proceed down the scale in the proper column to the line opposite your approximate CO_2 percentage as previously determined (extreme left hand column). The heat loss will be found at the junction of these two lines.

Note: The figures given on the reverse side are based on the fuel analyses given below. This should be taken into consideration when figuring your own heat loss.

Example: Suppose you are burning natural gas and your flue gas temperature is 625°F with room temperature at 65°F. The difference is 560°. Find this number on the scale. Suppose your CO_2 was found to be 6%. Proceeding down the "560" column to the CO_2 line of 6%, you will find the figure 30. *This* is the percent of *total heat loss* in the flue gas.

How much of this total loss is PREVENTABLE depends upon how high the CO_2 content of the flue gases can be raised and how low the flue gas temperature can be reduced without producing CO or increasing other losses such as carbon (smoke) or ash pit losses.

Carrying on with our example: if, by test or

PRODUCER GAS

computation, it is determined that the CO_2 can be raised to 9.5% and the difference between flue gas and room temperatures can be reduced to 400° the total heat loss in the flue gas would be 19.5%. This represents a saving of 10.5% in HEAT.

THE SAVING IN FUEL

The saving in *fuel* is even greater. With a 30% loss, 70% of the heat is being used while with a 19.5% loss, 80.5% of the heat is being used. The consumption of fuel at the higher efficiency is therefore equal to 70 ÷ 80.5 or 87% of that used when burned at the lower efficiency. The actual saving in FUEL is therefore 100% – 87% or 13%. It is, of course, necessary that the rate of steam generation remains constant, that the fuel quality be the same and that no CO be produced or the amount of smoke or ash pit losses increased while obtaining the higher percentage of CO_2.

FOR THE SAME FUELS OF BTU CONTENT OTHER THAN THOSE LISTED

For the same fuels of BTU content other than those listed, use the scale of the fuel which has the nearer BTU value. The errors involved are:

For COAL ± 2% of the calculated fuel saving. **Example:** If the calculated fuel saving is 5%, the actual saving will be between 4.9% and 5.1%.

For OIL ± 5% of the calculated fuel saving.

For NATURAL GASES ± 2% of the calculated fuel saving.

For MANUFACTURED GASES the error may be as great as 20% of the calculated value depending upon the composition of the gas.

FUEL ANALYSES

Natural Gas
(Heat Value 1120 BTU/CU. FT.)

	% by volume
CH_4	79.9
C_2H_6	17.3
CO_2	0.3
N_2	2.5

Producer Gas
(Heat Value 165 BTU/CU. FT.)

	% by volume
CO	24.9
CH_4	2.3
C_3H_4	0.9
H_2	14.5
CO_3	4.7
N_3	52.7

REFERENCE 8.

SCALE OF TOTAL HEAT LOSS – NATURAL GAS

% CO_2	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	23.1	24.4	25.9	27.2	28.6	30.0	31.3	32.8	34.1	35.8	36.9	38.2	39.8	41.0	42.2	43.8	45.0	46.3	47.8	49.0	50.0											
3.5	21.2	22.5	23.8	24.9	26.1	27.2	28.4	29.6	30.9	32.0	33.2	34.4	35.8	36.8	37.9	39.2	40.3	41.6	42.8	43.8	45.0	46.2	47.7	48.3	49.8							
4.0	19.9	20.9	22.0	23.1	24.1	25.1	26.2	27.2	28.3	29.4	30.4	31.8	32.5	33.8	34.8	35.8	36.8	37.8	38.8	39.9	40.9	42.1	43.0	44.1	45.2	46.2	48.8					
4.5	18.9	19.9	20.9	21.8	22.7	23.6	24.5	25.5	26.4	27.3	28.3	29.2	30.2	31.2	32.2	33.0	34.0	34.9	35.9	36.8	37.8	38.6	39.8	40.4	41.5	42.6	44.8	47.2	49.8			
5.0	18.0	18.9	19.8	20.6	21.4	22.2	23.1	24.0	24.9	25.8	26.8	27.5	28.3	29.1	30.1	30.9	31.8	32.5	33.6	34.3	35.7	36.2	36.9	37.8	38.8	39.7	41.8	43.8	46.0	48.2		
5.5	17.4	18.1	18.9	19.8	20.5	21.2	22.1	22.9	23.8	24.5	25.2	26.2	26.9	27.8	28.5	29.2	30.0	30.8	31.8	32.3	33.2	34.1	34.9	35.8	36.3	37.3	39.2	41.0	43.0	45.3	47.2	49.0
6.0	16.8	17.4	18.2	18.9	19.6	20.4	21.1	21.8	22.7	23.3	24.1	24.9	25.5	26.2	27.0	27.8	28.4	29.2	30.0	30.8	31.5	32.2	32.9	33.8	34.3	35.2	36.8	38.8	40.4	42.5	44.3	46.2
6.5	16.3	16.9	17.6	18.4	19.0	19.8	20.4	21.1	21.8	22.4	23.2	23.8	24.5	25.2	25.9	26.5	27.2	27.9	28.7	29.2	30.0	30.9	31.4	32.1	32.8	33.5	34.6	36.8	38.4	40.3	42.0	43.8
7.0	15.8	16.5	17.1	17.8	18.4	19.1	19.8	20.4	21.0	21.8	22.3	22.9	23.6	24.2	24.9	25.5	26.2	26.8	27.4	28.0	28.8	29.4	30.0	30.8	31.2	32.0	33.8	35.3	36.8	38.3	40.0	41.8
7.5	15.5	16.1	16.7	17.2	17.9	18.5	19.1	19.8	20.3	20.9	21.5	22.2	22.8	23.3	24.0	24.6	25.2	25.8	26.4	26.9	27.7	28.2	28.8	29.4	30.1	30.8	32.2	33.8	35.2	36.8	38.3	39.9
8.0	15.2	15.7	16.3	16.9	17.4	18.0	18.6	19.2	19.8	20.3	20.9	21.5	22.1	22.8	23.2	23.8	24.4	25.0	25.5	26.0	26.7	27.2	27.8	28.4	29.0	29.5	31.0	32.4	33.8	35.4	36.8	38.2
8.5	14.9	15.4	15.9	16.5	17.1	17.6	18.2	18.7	19.3	19.8	20.4	20.9	21.4	22.0	22.5	23.1	23.7	24.2	24.8	25.3	25.8	26.4	26.9	27.4	28.1	28.6	29.9	31.3	32.8	34.2	35.4	36.8
9.0	14.6	15.2	15.7	16.2	16.6	17.2	17.8	18.3	18.8	19.3	19.9	20.4	20.9	21.4	21.9	22.5	23.0	23.5	24.1	24.5	25.2	25.8	26.2	26.7	27.2	27.8	29.0	30.3	31.8	33.0	34.3	35.7
9.5	14.4	14.9	15.4	15.9	16.4	16.9	17.4	17.9	18.4	18.9	19.5	19.9	20.5	20.9	21.4	21.9	22.4	22.9	23.4	23.8	24.4	24.9	25.4	25.9	26.4	26.9	28.2	29.4	30.8	32.0	33.3	34.5
10	14.2	14.6	15.2	15.6	16.1	16.6	17.1	17.5	18.1	18.5	19.0	19.5	20.0	20.4	20.8	21.4	21.8	22.4	22.8	23.3	23.8	24.2	24.8	25.2	25.8	26.2	27.4	28.6	29.8	31.2	32.2	33.4
11		14.4	14.7	15.2	15.6	16.1	16.5	16.9	17.4	17.8	18.4	18.8	19.3	19.6	20.2	20.5	20.9	21.4	21.9	22.3	22.8	23.2	23.7	24.2	24.6	25.0	26.2	27.2	28.3	29.5	30.8	31.8
12			14.4	14.8	15.2	15.6	16.1	16.5	16.9	17.3	17.8	18.2	18.6	19.0	19.4	19.8	20.2	20.6	21.1	21.4	21.9	22.3	22.8	23.2	23.6	24.0	25.1	26.1	27.2	28.3	29.2	30.3

SCALE OF TOTAL HEAT LOSS – PRODUCER GAS

% CO_2	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	32.4	35.0	37.7	40.1	42.9	45.4	48.0	50.8	53.2	55.9	58.5	61.4	63.7	66.3	69.2																	
3.5	28.8	30.9	33.2	35.5	37.8	39.9	42.1	44.4	46.8	49.0	51.4	53.6	55.8	57.9	60.4	62.5	64.9	67.0	69.3													
4.0	25.9	27.9	29.9	31.9	33.9	35.9	37.9	39.8	41.9	43.9	45.9	47.9	49.8	51.7	53.8	55.8	57.8	59.8	61.5	63.5	65.5	67.8	68.8									
4.5	23.9	25.6	27.4	29.1	31.9	32.8	34.3	36.2	38.0	39.9	41.7	43.5	45.1	46.9	48.9	50.8	52.1	53.9	55.5	57.4	59.4	61.0	62.9	64.5	66.5	68.3						
5.0	22.2	23.9	25.3	26.9	28.6	30.1	31.8	33.5	35.0	36.9	38.3	39.9	41.3	43.2	44.7	46.3	47.8	49.5	51.0	52.5	54.2	55.9	57.5	59.0	60.9	62.3	66.4					
5.5	20.8	22.2	23.8	25.1	26.6	28.0	29.5	30.9	32.5	33.9	35.3	37.0	38.5	39.7	41.2	42.9	44.1	45.6	47.2	48.5	49.9	51.5	53.0	54.5	55.8	57.4	61.0	65.5	68.4			
6.0	19.7	20.9	22.3	23.7	25.0	26.4	27.8	29.0	30.5	31.9	33.2	34.5	35.8	37.3	38.8	39.9	41.2	42.8	43.8	45.3	46.5	48.0	49.4	50.9	52.0	53.4	56.9	60.1	63.5	67.0		
6.5	18.6	19.9	21.2	22.4	23.8	24.9	26.2	27.4	28.7	30.0	31.3	32.7	33.7	35.1	36.4	37.6	38.9	39.9	41.2	42.5	43.8	45.3	46.2	47.5	48.9	50.0	53.5	56.4	59.5	62.5	65.8	69.0
7.0	17.8	19.0	20.3	21.3	22.5	23.7	24.8	25.9	27.1	28.4	29.5	30.8	31.9	33.2	34.2	35.4	36.7	37.7	38.9	39.9	41.3	42.5	43.5	44.5	45.8	47.0	49.9	53.0	55.8	58.9	61.8	64.5
7.5	17.2	18.2	19.4	20.4	21.5	22.7	23.7	24.8	25.9	27.0	28.1	29.2	30.3	31.4	32.5	33.5	34.8	35.8	36.9	37.8	39.2	40.3	41.2	42.4	43.5	44.5	47.3	49.9	52.9	55.5	58.2	61.0
8.0	16.5	17.6	18.6	19.6	20.7	21.7	22.7	23.8	24.8	25.8	26.9	27.8	28.8	29.9	31.2	31.9	33.2	34.0	35.2	36.0	37.2	38.2	39.2	40.3	41.3	42.4	44.9	47.5	49.9	52.5	55.3	57.8
8.5	15.9	16.9	17.9	18.8	19.8	20.8	21.7	22.8	23.8	24.7	25.7	26.7	27.7	28.6	29.6	30.8	31.5	32.5	33.5	34.4	35.5	36.5	37.5	38.5	39.3	40.4	42.9	45.2	47.5	50.0	52.5	55.0
9.0	15.5	16.4	17.4	18.2	19.1	20.1	20.9	21.9	22.8	23.8	24.7	25.7	26.6	27.5	28.4	29.3	30.2	31.2	32.1	33.0	33.9	35.0	35.8	36.9	37.8	38.8	41.0	43.4	45.5	47.9	50.4	52.5
9.5	15.0	15.9	16.8	17.6	18.5	19.4	20.3	21.1	22.1	22.9	23.8	24.7	25.6	26.5	27.4	28.1	29.0	29.9	30.9	31.5	32.6	33.5	34.4	35.2	36.2	37.2	39.3	41.5	43.7	45.9	48.0	50.4
10	14.7	15.5	16.3	17.2	17.9	18.8	19.7	20.4	21.4	22.2	23.1	23.9	24.7	25.6	26.4	27.2	28.1	28.9	29.8	30.5	31.5	32.4	33.1	33.9	34.9	35.5	37.8	39.8	41.9	44.1	46.3	48.4
11	13.9	14.8	15.5	16.3	17.0	17.8	18.6	19.3	20.1	20.9	21.7	22.4	23.2	24.0	24.8	25.5	26.3	27.1	27.8	28.5	29.3	30.3	30.9	31.8	32.5	33.3	35.3	37.3	39.2	41.0	43.0	44.8
12	13.4	14.1	14.8	15.8	16.3	16.9	17.7	18.3	19.1	19.8	20.5	21.2	21.9	22.7	23.4	24.1	24.8	25.5	26.1	26.9	27.7	28.4	29.0	29.8	30.5	31.2	33.0	34.9	36.6	38.5	40.3	41.8
13	12.8	13.6	14.3	14.9	15.6	16.3	16.8	17.5	18.3	18.8	19.6	20.2	20.8	21.6	22.1	22.8	23.5	24.2	24.8	25.4	26.1	26.9	27.5	28.1	28.8	29.5	31.2	32.9	34.5	36.2	37.7	39.5
14	12.5	13.1	13.7	14.4	14.9	15.6	16.3	16.8	17.4	18.1	18.7	19.3	19.9	20.6	21.1	21.8	22.4	23.1	23.7	24.3	24.9	25.6	26.1	26.8	27.4	27.9	29.6	31.2	32.8	34.3	35.7	37.5
15	12.2	12.8	13.4	13.9	14.4	15.1	15.7	16.3	16.8	17.4	17.9	18.6	19.1	19.8	20.3	20.8	21.5	22.1	22.7	23.2	23.8	24.5	24.9	25.6	26.2	26.8	28.2	29.8	31.3	32.8	34.3	35.4
16		12.4	12.9	13.4	14.0	14.6	15.2	15.7	16.3	16.8	17.4	17.8	18.4	18.9	19.6	20.1	20.7	21.2	21.7	22.2	22.8	23.5	23.9	24.5	25.1	25.7	27.0	28.4	29.8	31.3	32.6	33.9
17		12.1	12.6	13.1	13.7	14.3	14.7	15.2	15.7	16.3	16.8	17.4	17.8	18.4	18.9	19.4	19.9	20.5	20.9	21.5	22.0	22.6	23.1	23.7	24.2	24.8	26.0	27.4	28.7	30.0	31.3	32.7

REFERENCE 8.

FIGURE HF 1-5

FIGURE HF 1-6

HOW TO FIGURE BITUMINOUS-COAL COMBUSTION QUICKLY

1. Kind of fuel .... Bituminous coal
2. Heating value as fired .... 13,800 Btu per lb
3. Room temperature .... 80 F
4. Flue-gas temperature .... 520 F
5. Flue-gas analysis:
   a. CO_2 .... 10.2%
   b. CO 0.6%
   c. O_2 .... 9.2%
6. Boiler efficiency (from test) 74.4%

COMPUTATIONS:

7. Theoretical air, from scale 1 .... 10.2 lb per lb fuel
8. Water produced by burning available hydrogen (scale 2) 0.35 lb per lb fuel
9. Total water from burning of coal = 0.35 + 0.05 = 0.40 lb per lb fuel
10. Actual air = 175% of theoretical = 1.75×10.2 = 17.9 lb per lb fuel
11. Total flue gas = air + coal − ashes = 17.9 + 1 − 0.2 = 18.7 lb per lb fuel
12. Dry flue gas = total flue gas − water produced = 18.7 − 0.40 = 18.3 lb per lb fuel
13. Sensible heat loss in dry gas = Dry gas weight × temperature rise × specific heat = 18.3 × (520—80) × 0.24 = 1930 Btu per lb fuel
14. Moisture heat loss per lb water = 1000 + ½ flue gas temperature = 1000 + 260 = 1260 Btu
15. Moisture heat loss = loss per lb water × lb water per lb coal = 1260 × 0.4 = 500 Btu per lb fuel
16. Incomplete-combustion loss, from chart 4 .... 3.2%
17. Heat balance

	Btu per lb fuel	%
a. Dry-gas loss	1,930	14.0
b. Moisture loss	500	3.6
c. Incomplete-combustion loss	440	3.2
d. Unaccounted-for losses	660	4.8
e. Total losses	3,530	25.6
f. Useful heat	10,270	74.4
g. Heating value, Btu per lb fuel	13,800	100.0

18. Calculation of heat balance items:
   a. Dry-gas loss = 1930/13,800 = 14.0%
   b. Moisture loss = 500/13,800 = 3.6%
   c. Incomplete combustion loss = 13,800×0.032 = 440 Btu per lb fuel
   d. Unaccounted losses = 3530−440—500−1930 = 660 Btu per lb fuel
   e. Useful heat = 13,800×0.744* = 10,270 Btu per lb

Short-cut Combustion Calculations

Every textbook on steam power plants has a complete demonstration on the calculation of fuel combustion. Such an exhibit usually assumes that complete fuel, flue-gas and refuse analyses are available. But many plants, especially in the smaller capacities, do not have such complete information and cannot justify the money needed to determine it. Nevertheless, to operate economically these plants should closely follow their combustion performance because it is at this point that efficiency can be made or broken.

Assuming that such a plant has instruments for analyzing flue-gas composition and measuring flue-gas temperature the method described here suffices to tell the operator whether his combustion conditions are proceeding satisfactorily or not. While the method is approximate, numerous checks have shown the results to be within 2% of those found by using the longer, complete methods. The operator must know his fuel type and its heating value in Btu per pound *as fired*. The fuel supplier can normally give this information with satisfactory accuracy.

Scales and charts forming the basis of this computing method are given on the facing page. Their use is demonstrated in the table above for a given set of data using bituminous coal as the fuel. Let's follow through on this table, item by item, to find out how the calculations are made.

Items 1 to 6 are the data that must be known as mentioned above. The boiler efficiency should preferably be known by test, but a guaranteed efficiency using the same fuel will do if test results are not available.

Item 7. Scale 1 under the appropriate fuel classification on the facing page gives the theoretical air requirement when the fuel heating value is known. In this computation method, note that all weights are given in pounds per pound of fuel as fired.

Item 8. Water in the flue gas originates from three sources: (1) water originally in the coal (2) water produced by the burning of available hydrogen in the fuel (3) moisture in the air supplied for combustion. Of these we shall figure only (2), which is five to ten times as much as the amount appearing in (1). We do not attempt to figure the value of (3) because it is very small and its variation unimportant from the angle of everyday operation. *Item 8* is found by using Scale 2 for the appropriate fuel.

Item 9. Since original moisture in coal is unknown we assume it to be 0.05 lb per lb of fuel. Any error in this assumption will be of little practical importance in figuring moisture heat loss later, except with lignite, wood and very wet coals.

Item 10. First add CO_2 and ½CO to find 10.2+½(0.6)=10.5. Use this value with Scale 3 for bituminous coal and read 75% excess air. On the lower scale it will be found that 9.0% O_2 corresponds to 75% excess air. This figure should be close to the O_2 value found by flue-gas analysis, which in this case was 9.2%. This is close enough to indicate a consistent gas analysis. If the CO_2 only should be known and the CO believed to be zero or negligible, enter Scale 3 with the CO_2 value to get the excess air magnitude.

Item 11. Practically speaking, everything fed to the furnace ultimately goes up the stack or into the ashpit. Then, to get the total weight of flue gas (per lb of coal fired) add 1 lb (of coal) to the air supplied and subtract the refuse produced per lb of coal. The refuse generally contains the original ash in the coal and perhaps some unburned carbon. Hence the amount of refuse is always greater or at least equal to the original ash weight in the coal, unless some ash is lost up the stack. Fortunately the refuse correction for the flue gas is not important. An error of 50% in the refuse allowance usually affects the total flue gas less than 1%. For practical purposes it is close enough (for any bituminous or anthracite coal) to assume 0.2 lb refuse *for this calculation.*

Item 12. Dry gas and water vapor in the flue gas must be separated to calculate the amount of heat energy carried off by each.

Item 13. Largest loss in boiler furnaces is the heat energy carried off by the dry gas. It is proportional to the amount of dry gas and the number of degrees above room temperature to which it is heated. These Btu loss figures are rounded off to the nearest 10 Btu. The method does not warrant closer figuring.

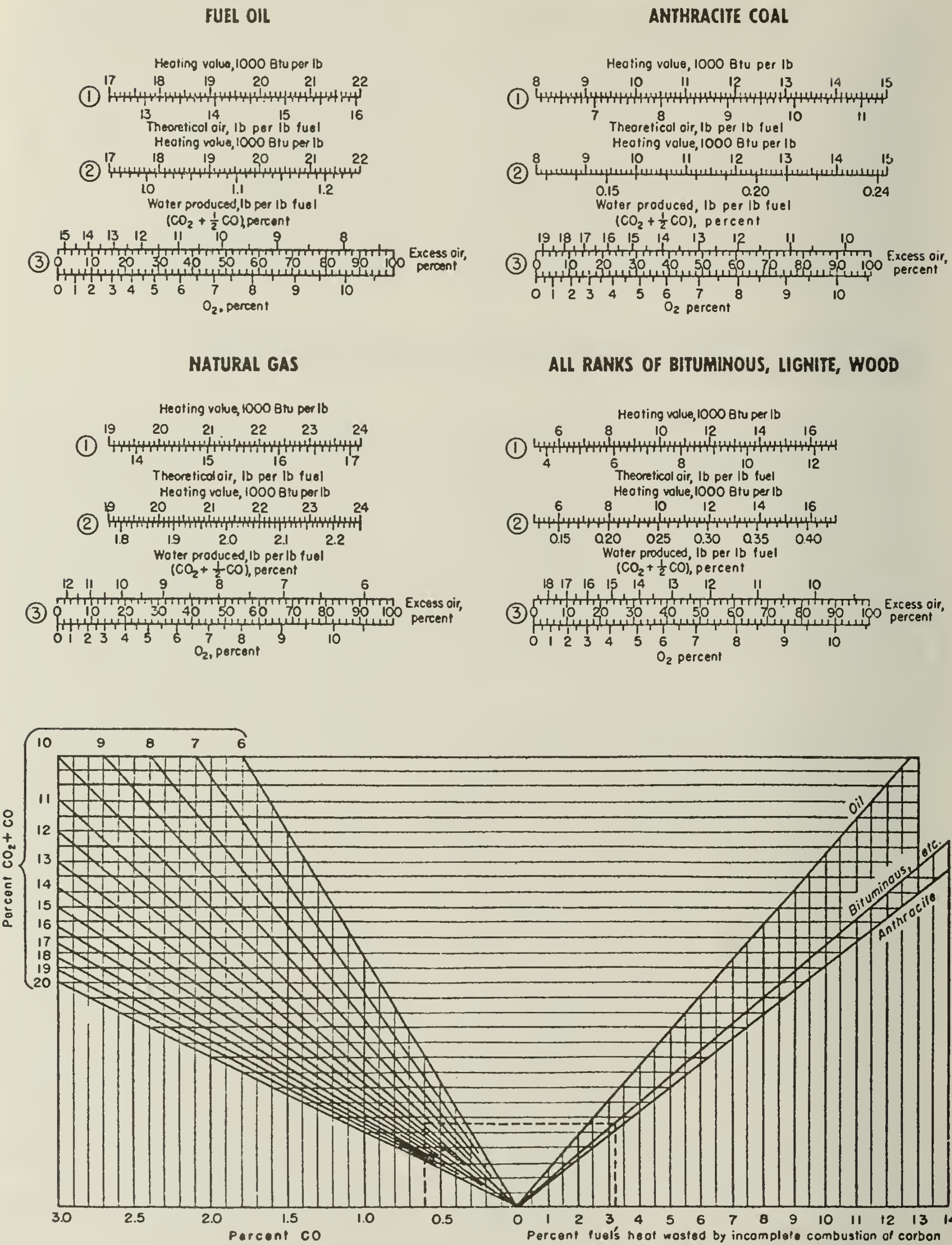
Item 14. Water in the coal as fired and the water produced by burning the fuel's available hydrogen must be heated to the boiling point, evaporated and then superheated to the flue-gas temperature. The formula given calculates the heat approximately needed to put 1 lb of water through these heating steps, starting with room temperature of 80 F. The formula is also suitable for room temperature ranging from 60 to 100 F.

Item 15. The previous step calculated the heat energy per lb of water; this formula corrects this figure to heat

REFERENCE 9.

FIGURE HF 1-7

SCALES AND CHART FOR COMBUSTION PERFORMANCE ESTIMATE



REFERENCE 9.

FIGURE HF 1-8

AIR REQUIRED FOR AND PRODUCTS OF COMBUSTION

Gives required combustion air and products for common combustibles burned with theoretical air requirements. Air and products are given in mols, cu ft and lb (see right-hand column) for 1 mol, 1 cu ft and 1 lb of fuel

Fuel	For 1 mol of fuel: Air O_2	Air N_2	Other products (than N_2) CO_2	H_2O	SO_2	For 1 cu ft of fuel: Air O_2	Air N_2	Other products (than N_2) CO_2	H_2O	SO_2	For 1 pound of fuel: Air O_2	Air N_2	Other products (than N_2) CO_2	H_2O	SO_2	
C	1.0	3.76	1.0	—	—	—	—	—	—	—	.0833	.313	.0833	—	—	Mols
	379	1425	379	—	—	—	—	—	—	—	31.6	118.8	31.6	—	—	Cu ft
	32.0	105	44.0	—	—	—	—	—	—	—	2.67	8.78	3.67	—	—	Pounds
H_2*	0.5	1.88	—	1.0	—	.00132	.00496	—	.00264	—	.250	.940	—	0.5	—	Mols
	189.5	712	—	—	—	0.5	1.88	—	—	—	94.8	356	—	—	—	Cu ft
	16.0	25.6	—	18	—	.0422	.139	—	.0475	—	8.0	26.3	—	9.0	—	Pounds
S	1.0	3.76	—	—	1.0	—	—	—	—	—	.0312	.1176	—	—	.0312	Mols
	379	1425	—	—	379	—	—	—	—	—	11.84	44.6	—	—	11.84	Cu ft
	32.0	105	—	—	64	—	—	—	—	—	1.0	3.29	—	—	2.0	Pounds
CO	0.5	1.88	1.0	—	—	.00132	.00496	.00264	—	—	.179	.0672	.0357	—	—	Mols
	189.5	712	379	—	—	0.5	1.88	1.0	—	—	6.77	25.4	13.53	—	—	Cu ft
	16.0	52.6	44.0	—	—	.0422	.139	.116	—	—	.571	1.88	1.57	—	—	Pounds
CH_4	2.0	7.52	1.0	2.0	—	.00528	.0198	.00264	.00528	—	.125	.470	.0625	.125	—	Mols
	758	2850	379	—	—	2.0	7.52	1.0	—	—	47.4	178	23.7	—	—	Cu ft
	64.0	210	44.0	36.0	—	.169	.556	.116	.0950	—	4.0	13.17	2.75	2.25	—	Pounds
C_2H_2	2.5	9.40	2.0	1.0	—	.0066	.0248	.00528	.00264	—	.0962	.362	.0769	.0385	—	Mols
	947	3560	758	—	—	2.5	9.40	2.0	—	—	36.4	137	29.15	—	—	Cu ft
	80.0	263	88.0	18.0	—	.211	.694	.232	.0475	—	3.08	10.13	3.38	.692	—	Pounds
C_2H_4	3.0	11.29	2.0	2.0	—	.00792	.0298	.00528	.00528	—	.1071	.403	.0714	.0714	—	Mols
	1137	4280	758	—	—	3.0	11.29	2.0	—	—	40.6	153	27.1	—	—	Cu ft
	96.0	316	88.0	36.0	—	.253	.834	.232	.0950	—	3.43	11.29	3.14	1.286	—	Pounds
C_2H_6	3.5	13.17	2.0	3.0	—	.00923	.0347	.00528	.0079	—	.1167	.439	.0667	.10	—	Mols
	1326	4990	758	—	—	3.5	13.17	2.0	—	—	44.2	166.3	25.3	—	—	Cu ft
	112.0	369	88.0	54.0	—	.296	.972	.232	.1425	—	3.73	12.29	2.93	1.8	—	Pounds

*Varying assumptions for molecular weight introduce a slight inconsistency in the values of air and combustion products from the burning of hydrogen. True molecular weight of hydrogen is 2.02, but the approximate value of 2 is used in figuring the air and combustion products.

energy per lb of fuel to be consistent.

Item 16. Loss due to incomplete combustion of the carbon to CO is found directly from the chart at the bottom of page 11f. Enter chart with 0.6% CO and move vertically up to slanting line equaling sum of CO_2 and CO, which is 10.8%. From this intersection move horizontally to right to line marked *Bituminous*, then down to lower right-hand scale showing percent of fuel's heating value wasted.

Item 17. By setting up the table shown with lines *a* to *g* all the foregoing calculations may be summarized by entering them in the proper spaces as shown in color. The calculations needed to fill the rest of the table are given in *Item 18* in correspondingly lettered lines.

The unaccounted losses as shown in *Item 13, line d*, are found by difference and here include chiefly: (1) loss of carbon to ashpit (2) radiation from boiler and furnace (3) cumulative error (plus or minus) of all data and computations. Any marked variation in this quantity should be cause for an operator to look for trouble in his steam generator unless he can account for it directly by known factors.

Carbon loss in refuse to the ashpit is usually figured from analyses of the coal and the refuse. The foregoing method assumes that no analyses are available. If the coal-ash content is known, the carbon loss can be calculated from measurements of coal fired and refuse produced. To illustrate let's assume the following data:

Ash in coal as fired, 7.4%; refuse produced per lb of coal, 0.096 lb. Then the refuse from each pound of coal fired must contain 0.096-0.074=0.022 lb of combustible material. Since this material will be pretty well "cooked" or heated to drive off the volatile gases, we can figure it as pure carbon with a heating value of 14,600 Btu per lb. Then carbon loss=0.022×14,600=320 Btu per lb fuel fired.

This method cannot be used where substantial amounts of carbon are lost up the stack, as in certain cases of pulverized fuel and stokers operating with heavy forced draft. Where carbon loss is figured it should, of course, be inserted in the heat balance, reducing the unaccounted losses by that amount.

As-fired vs Dry. The heating value and analysis of fuel as fired varies with the amount of moisture associated with it. The moisture, in turn, constantly changes in amount during mining, shipping and storing. Hence, chemists and coal men sometimes prefer to quote the analysis of dry coal and give the moisture separately.

But all the foregoing computation and charts in this section are based on fuel as fired. If coal data are given on the dry basis they must be converted to the as-fired basis. For instance, let's assume that coal on the dry basis has 12,700 Btu per lb and 12.4% ash. If the as-fired coal has a moisture content of 4.5%, the conversion constant is 1.00−0.045=0.955. Then multiply the dry-basis figure by 0.955 to get the as-fired figure, or 12,700×0.955=12,130 Btu per lb as-fired coal.

This shortcut method was designed for the engineer who wants his answer quickly though his technical resources are limited. Combustion technicians in large power plants and others who make elaborate boiler tests and studies have all the paraphernalia for a complete analysis based on chemical relations. This method is not intended for their use.

Calculation Data. Above table is compiled for the engineer who must deal with many fuels and their combustion. It gives basic data on relation between elements in the combustion process on (1) the mol basis (2) the volumetric basis and (3) the weight basis. Study of the table will show that it enables the rapid conversion of any calculation from one base to any of the two other bases with a minimum of both time and error.

Each of the three groups of columns refers to one of the calculating bases. For example, the first group of columns refers to the mol basis, that is, one mol of the fuel element shown in the first column. The first line in each box gives the corresponding mols of oxygen and nitrogen in air needed for burning this element or the number of mols of combustion products resulting from the completed reaction.

FIGURE HF 2-1

COST OF STEAM ATOMIZATION VERSUS AIR ATOMIZATION

1. Boiler Model No. ____________

2. Maximum Continuous Capacity ____________ lb/hr

3. Operating Pressure ____________ psig

4. Water Temperature at Main ____________ °F

5. Boiler Efficiency (see Sales Manual) ____________ %

6. Boiler Exit Gas Temperature ____________ °F

7. Cost of Number ______ Fuel Oil ____________ \$/gal

8. Btu Value of Fuel Oil

   #2 Fuel Oil 140,890 Btu/gal
   #4 Fuel Oil 144,400 Btu/gal
   #5 Fuel Oil 148,520 Btu/gal
   #6 Fuel Oil 151,700 Btu/gal ____________ Btu/gal

9. Steam Required to Atomize Fuel Oil (1 to 2%) of Steam Capacity ____________ %

10. Enthalpy of Steam at ________ psig (See Steam Tables ____________ Btu/lb

11. Enthalpy of Water from Main at _______ °F (See Steam Tables) ____________ Btu/lb

12. Enthalpy of Atomizing Steam at Boiler Outlet Flue Gas Temperature ______ °F and at zero (0) psig gauge or 14.7 psig absolute (See Steam Tables) ____________ Btu/lb

13. Heat Loss ____________ Btu/lb
    (Item 12 - Item 11) (_______ - _______) =

14. Total Heat Required per lb of Steam ____________ Btu/lb
    $\left(\text{Item 13} \div \frac{\text{Item 5}}{100}\right.$ $\left(\_\_\_\_\_\_\_ \div \frac{\_\_\_\_\_\_\_}{100}\right) =$

15. Steam Required to Atomize Fuel Oil ____________ lb/hr
    $\left(\text{Item 2} \times \frac{\text{Item 9}}{100}\right.$ $\left(\_\_\_\_\_\_\_ \times \frac{\_\_\_\_\_\_\_}{100}\right) =$

REFERENCE 11.

FIGURE HF 2-1(cont'd)

16. Total Heat Required to Steam Atomize ____________ Btu/hr
(Item 15 x Item 14) (________ x ________) =

17. Fuel Required to Generate Steam to Atomize ____________ gal/hr
Fuel Oil
(Item 16 ÷ Item 8) (____________ ÷ __________) =

18. Cost of Fuel to Generate Atomizing Steam ____________ $/hr
(Item 17 x Item 7) (________ x ________) =

AIR ATOMIZATION

19. Compressor motor horsepower rating
Actual hp required at max. capacity ____________ hp

20. Power required (Item 19 x .746 hp/Kw) (_______ x .746) = ____________ Kw

21. With motor efficiency @ 85% (Item 20 ÷ .85) (_____ x .85) = ____________ Kw

22. Power Cost ____________ $/Kw

23. Cost of Atomizing Air (Item 21 x Item 22) (_______ x _____)= ____________ $/hr

EVALUATION

24. Cost for Steam Atomization (Item 18) ____________ $/hr

25. Cost for Air Atomization (Item 23) ____________ $/hr

26. SAVINGS (Item 24 minus Item 25) (________ - ________) = ____________ $/hr

TOTAL OPERATIONAL SAVINGS

27. Dollar savings at maximum continuous capacity for one (1) yr
(Item 26 x 8,000 hours) (__________ x __________) = ____________ $/hr

28. Fuel savings, full year
(Item 27 ÷ Item 7) (_________ ÷ _________) = ____________ gal/yr

29. Dollar savings for a 20-year period
Item 27 x 20) (_________ x 20) = ____________ $/20 yrs

30. Dollar savings at 60% load (operating) factor for one (1) yr
Item 27 x .60) (__________ x .60) = ____________ $/yr

31. Fuel savings at 60% load factor
(Item 30 ÷ Item 7) (___________ ÷ _________) = ____________ gal/yr (60%)

32. Dollar savings at 60% load (operating) factor for 20 yrs
(Item 30 x 20) (_________ x 20) = ____________ $/20 yr (60%)

REFERENCE 11.

APPENDIX TO ECO W-2

A. DOMESTIC HOT WATER FIXTURE FLOW

Discharge pressure, flow and temperature for various fixtures both with open spouts and flow restrictors are presented in Table W 2-1. Required hot water flows to achieve desired fixture discharge temperature are presented for selected hot water supply temperatures and an assumed cold water supply temperature of 50°F.

The discharge from lavatory fixtures with open spouts at 45 psig is typically 4.5 gpm. For a desired outlet temperature of 105°F and a hot water supply temperature of 200°F, 37 percent of the fixture flow or 1.05 gpm is hot water supply. If the hot water supply temperature is reduced to 110°F, 92 percent of the fixture flow or 4.14 gpm is hot water supply.

Flow restrictors to limit hot and cold water flow to 1.5 gpm each may be provided on the water supply piping to lavoratory fixtures. In this event, with a hot water supply of 140°F and a maximum hot water flow of 1.5 gpm, only .96 gpm of cold water is required to maintain a desired fixture outlet temperature of 105°F. Total fixture outlet flow reduces to 2.46 gpm. If the hot water supply temperature is reduced to 110°F, again at a maximum hot water flow of 1.5 gpm, then the cold water flow must be further reduced to .13 gpm to maintain a desired fixture outlet temperature of 105°F.

The discharge from sinks with open spouts at 45 psig is typically 9.5 gpm at a temperature of 110°F. As hot water supply temperature is decreased from 200 to 140°F, hot water flow must increase from 3.8 to 6.37 gpm. After installing 3.0 gpm flow restrictors on hot and cold water inlets, fixture outlet flow decreases from 9.5 gpm to 4.48 gpm while maintaining a constant outlet temperature of 110°F with a hot water supply temperature of 140°F.

The discharge from shower arms with open spouts at 45 psig is typically 6.25 gpm at a temperature of 105°F. Flow restrictors may be installed on the shower arm to limit outlet flow to 3 gpm. Since the total flow is reduced after blending, hot and cold water requirements are both reduced in direct proportion in maintaining a desired outlet temperature.

TABLE W 2-1
TYPICAL FIXTURE FLOWS

	FIXTURE OUTLET			HOT WATER		
	Press. (psig)	Flow (gpm)	Temp (°F)	Temp (°F)	Percent of Outlet Flow	Flow (gpm)
A. LABORATORY						
1. Open Spout	45	4.5	105	200	37	1.05
	45	4.5	105	140	61	2.75
	45	4.5	105	120	79	3.56
	45	4.5	105	110	92	4.14
2. 1.5 GPM Max Flow Control On Hot Water Supply	45	2.46	105	140	61	1.5
	45	1.89	105	120	79	1.5
	45	1.63	105	110	92	1.5
B. SINK						
1. Open Spout	45	9.5	110	200	40	3.8
	45	9.5	110	140	67	6.37
2. 3.0 GPM Max Flow Control on Hot Water Supply	45	4.48	110	140	67	3.0
C. SHOWER						
1. Open Spout	45	6.25	105	200	37	2.31
	45	6.25	105	140	61	3.81
	45	6.25	105	120	79	4.94
2. 3.0 GPM Total Flow Control On Shower Arm	45	3.0	105	140	61	1.83
	45	3.0	105	120	79	2.37

B. FEASIBILITY OF FLOW CONTROL

The feasibility of the installation of flow restrictors depends upon the number of daily users and useage time. These parameters must be determined from field observation. Typical feasibility analysis for the installation of flow restrictors on lavoratories is presented in the following paragraphs.

4.B.1 Capital Investment Cost: The estimated capital cost for installing flow control fittings on the hot and cold water supply to a lavoratory is $25.

4.B.2 Useage Criteria: Useage criteria are assumed as follows:

a. persons per lavoratory fixture	7
b. useage per person per day	4
c. time per useage	15 sec.
d. working days per year	248 days
e. water temperature	
(1) hot water supply	120°F
(2) cold water supply	50°F
(3) fixture outlet	105°F
f. water flow (refer to Table W 2-1)	
(1) open spout	
(a) hot water supply	3.56 gpm
(b) cold water supply	.94 gpm
(c) fixture outlet	4.5 gpm

(2) flow restrictor

(a) hot water supply 1.5 gpm

(b) cold water supply .39 gpm

(c) fixture outlet 1.89 gpm

g. energy equivalent

(1) steam conversion to hot water 1000 Btu/lb steam

(2) fuel to generate steam 1390 Btu/lb steam

4.B.3 <u>Present Energy Consumption with Open Spout</u>:

a. hot water useage:

$$7 \times 4 \times 15 \times \frac{1}{60} \times 3.56 = 24.9 \text{ gpd.}$$

b. energy consumption:

$$24.9 \times 8.33 \text{ lb/gal} \times (120-50) \times 1 \text{ Btu/lb-}^{o}\text{F} = 14519 \text{Btu/d}$$

4.B.4 <u>Projected Energy Consumption with Flow Restrictor</u>:

a. hot water consumption

$$7 \times 4 \times 15 \times \frac{1}{60} \times 1.5 = 10.5 \text{ gpd.}$$

b. energy consumption:

$$10.5 \times 8.33 \text{ lb/gal} \times (120-50) \times 1 \text{ Btu/lb-}^{o}\text{F} = 6123 \text{Btu/day}$$

4.B.5 <u>Energy Savings</u>

a. Btu Savings

(14519-6123) x 248 = 2,082,000 Btu/year

b. Steam Savings

$$\frac{2{,}082{,}000}{1{,}000} = 2{,}082 \text{ lbs steam/year}$$

c. Fuel Savings

$$2{,}082 \times 1390 \times 10^{-6} = 2.89 \text{ MMBtu/year}$$

4.B.6 Btu Savings/Investment Dollar

$$\frac{\text{Capital Investment}}{\text{MMBtu/year}} = \frac{25}{2.89} = \$8.65/\text{MMBtu/year}$$

4.B.7 Savings/Investment Ratio (SIR)

The cost of fuel for steam generation is estimated as $2.90 per 10^6 Btu equivalent of steam. Assuming a 9 percent differential inflation rate and a 10 percent discount rate, the present value of fuel cost savings over a twenty five year period is:

$$2{,}082 \times 1000 \times 10^{-6} \times \$2.90 \times 22.351^{*} = \$134.95$$

*present value factor

$$\text{SIR} = \frac{\text{Savings present worth}}{\text{Capital Investment}} = \frac{134.95}{25} = 5.40$$

SIR greater than 1.0 indicates that the proposed investment is cost-effective.

4.B.8 Discounted Payback

The discounted payback period for the investment assuming a 10 percent discount rate and twenty five year life is 1.9 years.

4.B.9 Conclusions

Based on the above criteria, the installation of flow restrictors on each lavoratory for 7 or more persons results in annual savings of approximately $130 after a payback period of approximately 2 years.

Appendix 5

APPENDIX 5

REFERENCES

NUMBER	TITLE	MENTIONED IN
1.	ASHRAE Handbook, "Systems", 1973	
2.	Engineering Weather Data Manual (AFM 88-8) of the Departments of the Air Force, Army and Navy dated 15 June 1976	Appendix 3
3.	ASHRAE Handbook, "Fundamentals," 1972, Chapters 2, 20, 21, 22	ECO SK 1.2
4.	ASHRAE Handbook, "Fundamentals," 1972, Page 344	ECO SK-2
5.	ASHRAE Transactions, Vol. 75, Part 2, Page 168	ECO SK-2
6.	ASHRAE Handbook, Systems, 1973, Chapter 3, Page 3.5, Co-author H.P. Becker	ECO SK-3
7.	HPAC, January 1960, "Roof Spraying Systems", W.O. Kind	ECO SK-4
8.	Data From Hays Corporation	ECO HF-1
9.	Data From Power Editorial Feature "Fuels & Firing"	ECO HF-1
10.	ASHRAE Journal, May 1973, "Conversion of Boilers to Dual Fuel"	ECO HF-1
11.	Cleaver Brooks Data, "Cost of Steam vs. Air Atomization"	ECO HF-2
12.	Power, 1975 Generation Handbook, "Stop Blowdown System Wear"	ECO HH-4
13.	HPAC, March 1967, "The Economics of Boiler Replacement", Wm. F. Zunker	ECO HH-6
14.	Johnson Corporation Bulletin, "Condensate Handling Systems"	ECO HCR-3
15.	Nash Engineering Co. Bulletin, "Multi-Phase Pump"	ECO HCR-3.4
16.	Cochrane Div., Crane Corporation	ECO HCR-3.4
17.	HPAC, March 1976, "Variable Volume Induction Systems"	ECO HA-1.3
18.	Mitco Corporation Conversion Manual	ECO HA-1.3

NUMBER	TITLE	MENTIONED IN
19.	HPAC, Nov. 1975, "Excessive Infiltration & Ventilation Air"	HA-1.1
20.	Actual Specifying Engineer, April 1974, "How to Select and Specify Time Controls", Donald Karman	
21.	Steam-It's Generation & Use, 1972	ECO WCF-1
22.	Amertap Corporation Bulletin 5M74	ECO D-3
23.	American M.A.N. Corporation Bulletin	ECO D-3
24.	Sprague Electric Co., Bulletin,"A Guide to Power Factor Correction"	Appendix 4

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